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DESIGN PRINCIPLES FOR WETLAND TREATMENT SYSTEMS

by

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Published data pertaining to the treatment of wastewater by 26 wetlands have been assembled and analyzed to identify general principles for successful design of wetland facilities. Source of operating data have been tabulated. Performance is correlated with overall system features but cannot be predicted on the current basis. A simplified compartment model is presented.

The selection of natural sites and the physical facilities associated with wetland treatment are discussed. A protocol for site review is presented. Operational techniques and the use of constructed (artificial) wetlands are also considered. Wastewater impact on wetland and the economics of wetland treatment are discussed.

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FOREWORD

EPA is charged by Congress to protect the Nation's land, air, and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise, and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life. In partial response to these mandates, the Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, is charged with the mission to manage research programs: to investigate the nature, transport, fate, and management of pollutants in ground water; to develop and demonstrate technologies for treating wastewater with soils and other natural systems; to control pollution from irrigated crop and animal production agricultural activities; and to develop and demonstrate cost-effective land treatment systems for the environmentally safe disposal of solid and hazardous wastes.

Natural wetlands provide an effective wastewater treatment system at less cost than conventional or advanced treatment systems. Published data on 26 existing systems have been assembled and analyzed to identify principles for successful design. Performance is correlated with overall system features and a simplified compartment model is presented.

Clinton W. Hall
Clinton W. Hall
Director, RSKERL

PREFACE

The treatment of wastewater by overland flow through a wetland is a new concept. Only in the last decade has the performance of such systems become a topic of scientific study. This is not to imply that wastewater discharge to wetland areas is a new practice, for a number of sites have been identified where discharge has been ongoing for more than half a century. New treatment systems are being established at natural wetlands and at wetlands specifically constructed for this purpose. Significant improvement in wastewater quality is generally observed, at a cost which is low when compared to other alternatives. It is essential that the information which is useful for the design of wetland systems be readily available to engineers, ecologists, and planners.

It is our purpose here to identify data sources, and to present certain design concepts and their application to wetland treatment. The topics discussed were selected partly of necessity on the basis of data availability. Designers of a wetland facility must address many complex, interdisciplinary issues. Not only must answers be found, but in many cases useful questions must first be formulated. The text which follows is not intended to constitute a comprehensive treatment of the subject. Further research is still needed to permit complete analysis of certain aspects of wetland system design.

The concepts and design techniques presented in the subsequent pages will hopefully facilitate the application of research to date. They may also suggest future directions for research studies to improve our ability to design reliable wetland treatment systems.

ABSTRACT

Published data pertaining to the treatment of wastewater by wetland irrigation have been assembled and analyzed to begin to identify general principles for successful design of wetland facilities. Sources of operating data have been tabulated. Performance is roughly correlated with overall system features, but cannot be predicted on the current basis. Existing compartmental models require more detailed information than does or will exist; thus a simplified compartment model is presented.

Water quality is controlled by rapid processes related to water movement, mass transport to other compartments, and consumption kinetics. Thus, wetland hydrology is fundamental to the analysis of water quality improvement. The ultimate fate of nutrients and contaminants is determined by sedimentation, biomass production and harvest, and soil and microbial processes. Required wetland area depends on effluent quality, ecosystem type and age, and hydraulic regime. These questions can be addressed in terms of a mass transport model for the zone of rapid removal, and a "saturation" model for the expansion of a zone of stabilzed activity about the discharge point. Material balances, considering only long-term consumption mechanisms for nutrients and other pollutants, determine the useful life and ultimate performance of a wetland system.

The selection of natural sites and the physical facilities associated with wetland treatment are discussed. A possible protocol for site review is presented. Operational techniques and the use of constructed wetlands are also considered. Finally, wastewater impacts on wetlands and the economics of wetland treatment are discussed.

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SECTION 1

INTRODUCTION

The function of wastewater treatment is to improve the quality of the effluent before its ultimate release to surface waters of lakes and streams or to ground water. Wetlands have been shown to be capable of removal of nutrients (phosphorus and nitrogen) and other wastewater components to very low levels, they therefore constitute advanced wastewater treatment (AWT) processes. The reliable design of a wetland treatment facility requires the development of performance equations which describe both the response of the ecosystem to wastewater additions and the alteration of water quality. These equations must be developed from the operating data of existing systems and from insight obtained from research studies conducted in the laboratory and at field sites.

The 26 projects listed in Table 1 represent the data upon which the following models are based. Further details of this data base are given in the Appendix. This list is incomplete for two reasons: some new projects have begun while this study was underway, and our focus has been primarily on North American sites. It is also known that there are a great number of unstudied wetland/wastewater systems. In the Midwest alone (EPA V) there are over 100 such sites (1). The data collected at any one site are often incomplete. Mass balances on water, or any other constituent of interest, are almost always lacking. Depths and flow patterns are generally not known, so residence times can only be estimated. New projects, now beginning, have been planned to obtain more specific design data than many of the pioneering studies available for this analysis.

Since experience is somewhat limited, only the basic features of the wetland treatment process are susceptible to meaningful analysis. These include wetland hydrology and overland flow, removal rates for wastewater components, and the effects of nutrient additions on the continued ability of a wetland to treat wastewater.

When wastewater is discharged to the surface of a wetland it flows away, spreading into a dynamic mound about the discharge point. The depth which will result depends upon the hydrological characteristics of the wetland. The faster the wastewater flow, the deeper the surface water. Therefore each wetland system will have a hydraulic capacity, which could change rapidly in response to rain or other hydrological factors. Depth limits will be determined by the tolerance of wetland vegetation and by consideration of operating factors such as residence time. Depth and velocity will also affect the ability of the wetland to remove pollutants from the surface waters.

TABLE 1. SITE SUMMARY LIST

Site	Approximate Age, yr.	Annual Discharge 10^6 gal.	Data Base Size	Identifying Number In Figures
Bellaire, MI	25	30	Small	2
Bradford, ONT	1	0.5	Small	-
Brillion, WI	56	98	Medium	4
Brookhaven, NY	6	3	Small	-
Clermont, FL	4	4	Medium	5
Cootes Paradise, ONT	52	-	Small	10
Drummond, WI	3	15	Small	-
Dulac, LA	2	0.03	Small	-
Gainesville, FL	7	6	Large	-
Great Meadows, MA	68	1600	Medium	6
Hamilton, NJ	2	1.7	Small	-
Hay River, NWT	16	11	Small	1
Houghton Lake, MI	4	100	Large	3
Humboldt, SASK	2	10	Small	-
Jasper, FL	60	-	-	-
Kesalahti, Finland	-	-	-	-
Kincheloe, MI	25	150	Small	-
Lake Balaton, Hungary	-	-	Small	-
Las Vegas, NV	60	30,000	Medium	-
Listowell, ONT	2	15	Medium	-
Mt. View, CA	7	255	Small	9
Seymour, WI	2	0.1	Small	11
Suisun, CA	5	20	Medium	-
Vermontville, MI	2	25	Small	-
Waldo, FL	46	30	Small	8
Wildwood, FL	20	55	Small	7

Hydrology of the wetland site is therefore crucial to the understanding of the treatment processes which occur. A discussion of wetland hydrology is included in Section 3.

The removal of wastewater components from the wetland surface waters is of primary concern to the designer. The rate at which this occurs will dictate the relationship between the wastewater inputs and the quality of the wetland effluent. These terms and other parameters such as removal efficiency, are interrelated through a material balance about the surface waters. Therefore, the removal rate for each component must be determined. These rates can vary with factors such as water flow rate, depth, season, species composition within the wetland, type of soil substrate, and the age of the treatment facility.

Prediction of removal rates, over time, is a primary task in the analysis of a wetland treatment system design. Two approaches to this problem will be discussed in subsequent sections. The first is the correlation of operating data from existing systems (Section 4), and the second is the development of a conceptual model for the wetland treatment system (Section 5). The synthesis phase of design and numerical applications of the wetland system model are discussed in Section 6, and Section 7, respectively.

While the wetland facility must fulfill its function of wastewater treatment, the impact of wastewater upon the pre-existing ecosystem of a natural marsh must also be considered at the design stage. Both short-term and long-term changes should be considered. The status of knowledge in this area is addressed in Section 8.

Evaluation of a proposed system design must ultimately turn to economics. The available data on capital requirements and operating expenses are discussed in Section 9.

SECTION 2

CONCLUSIONS

Selection of equipment and materials for wetland wastewater treatment systems follows conventional engineering practices. The principal difficulty is predicting the performance and age of a proposed facility. The impact of wastewater upon the wetland ecosystem must be considered as part of the design process.

Data from existing wetland treatment systems are as yet insufficient to provide complete performance correlations for use in design of new facilities. However, the assembled research findings have made it possible to describe the wetland wastewater treatment process by a two step model-pollutant transport and pollutant consumption. Since nutrients, heavy metals, and other contaminants are consumed or immobilized primarily at solid surfaces within the wetland ecosystem, they must first be transported through the water sheet. The subsequent uptake mechanisms are numerous and complex. A complete material balance on the surface water sheet, coupled with rate equations for long-term pollutant removal mechanisms provide a basis for meaningful design calculations.

Transport phenomena are determined by site topography and hydrology. Wetland areas which have not been previously exposed to wastewater show rapid removal of pollutants from flowing surface waters. The overall process is rate-controlled by mass transfer. The delivery of nutrients and other materials to the wetland surfaces is slower than their consumption. This process can be described in terms of site hydrology and convective mass transfer coefficients.

The ageing effects observed in wetland treatment systems can be attributed to changes in the rate-controlling mechanism for pollutant removal. Certain consumption processes, such as adsorption and biomass pool expansion, exhibit "saturation" phenomena, while other mechanisms such as soil building and microbial activity continue at an undiminished rate. Saturated mechanisms result in a zone of reduced pollutant removal near the wastewater discharge. This zone will expand with continued wastewater irrigation, requiring a larger wetland area to achieve an equivalent improvement in water quality. The expansion of this zone can be predicted by a material balance and knowledge of certain site-specific rate parameters related to the vegetation, soil, and other ecosystem features.

SECTION 3

WETLAND HYDROLOGY

The design or evaluation of wetland wastewater treatment systems requires a sound understanding of the marsh hydrology. Surface water flow rates, soil infiltration, and depth are of primary concern. The performance of wetland wastewater treatment systems will depend upon prevailing hydrological conditions. Water depths and flow rates are usually determined by natural stream flows, overland flow, precipitation, and evapotranspiration. Introduction of wastewater irrigation may result in localized increases in water depths, which in turn, combined with increased nutrients, may cause changes in the species composition of the plant and animal communities. Removal of nitrogen, phosphorus, and other pollutants is best accomplished by slow overland flow of surface waters in a thin sheet, or by infiltration. Channelized flow, characterized by greater water depths and shorter residence times tends to reduce the system's effectiveness for pollutant removal.

In order to properly assess the performance of a wetland, a complete water budget must be prepared. All points of influx and efflux must be identified and the flows estimated throughout the year. Similarly, precipitation and evapotranspiration must be quantified. This water budget, illustrated on Figure 1, when combined with measurements of nutrient concentrations, can provide a complete picture of the wetland treatment system performance. Concentration values at the inlet and outlet of any system are only part of the picture, and can be misleading if the inflow and outflow of water are not identical. If not taken into account, infiltration, dilution of wastewater by flowing surface waters or by rain, or concentration of solids due to evapotranspiration can confuse the interpretation of system performance.

THE WATER BUDGET

The annual water budget of any region in a wetland can be expressed as an unsteady-state material balance of the form:

$$Q_i - Q_o + A + P - E - I = \Delta M \qquad [3.1]$$

where Q_i = flow in, m^3

Q_o = flow out, m^3

A = wastewater additions, m^3

P = precipitation, m^3

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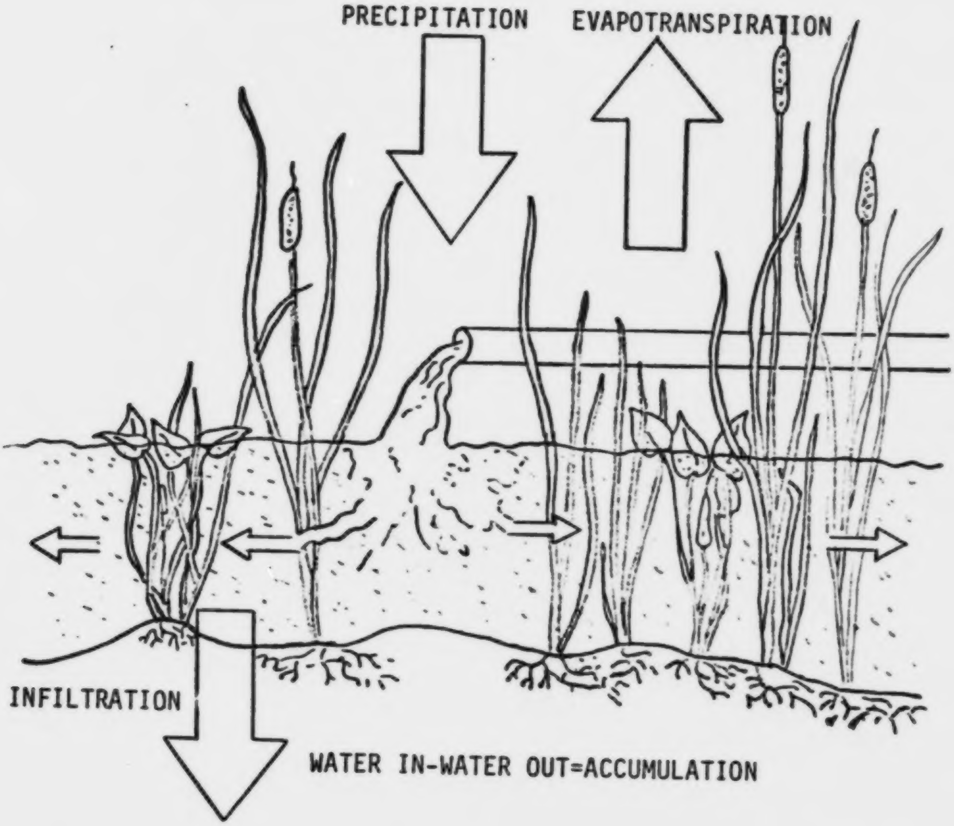

PRECIPITATION
EVAPOTRANSPIRATION
INFILTRATION
WATER IN-WATER OUT=ACCUMULATION

Figure 1. Establishing the Water Budget.

E = evapotranspiration, m^3

I = downward infiltration through the soil, m^3

M = above ground water accumulation, m^3

Surface water depth, denoted as h, can be related directly to the accumulation term, ΔM, so long as there is standing water

$$h = (M/s\phi_S) \qquad [3.2]$$

where h = water depth, m

s = surface area of region, m^2

ϕ_S = fraction of wetland volume, above ground, available for water storage, dimensionless.

Should the above ground water accumulation become negative, no surface water exists. Under these conditions the soil is no longer saturated. Due to the hygroscopic nature of peat and typical wetland organic substrates, it is generally impossible to measure the elevation of the below ground water table by usual techniques.

Closure on the wetland water budget is necessary before the performance of an existing system can be meaningfully evaluated. Inflows and outflows must be identified and measured. Precipitation figures are normally available from official weather records. Evapotranspiration can be estimated using techniques which will be discussed subsequently. Infiltration flows can be estimated by examination of soil borings and determination of the permeability of underlying soils. Such flows can more often be determined only by the discrepancy in closure on the water balance.

Similarly the water budget is essential to prediction of new system performance. In this case, future inflows must be estimated, and precipitation predicted from historical weather data. Infiltration/percolation can only be estimated by examining soil cores. Outflows will be system dependent and can be predicted by estimating both the expected evapotranspiration and the rate of overland water flow.

WETLAND WATER FLOW

The rate at which water can flow across a wetland is controlled by the ground slope, water depths, type of vegetation, and by the degree and type of channelization. The flow is not only related to water depth by the water balance equation, but also by an appropriate expression which relates the water velocity to driving forces (hydraulic gradient) and resistances.

Typical water depths in a wetland may range from a few centimeters to about one meter. Spatial variations in depth within a wetland are largely due to changes in the elevation of the underlying soil. The water pool is relatively flat with very small surface gradients. Wastewater, introduced to the wetland, will spread from the discharge points, and if the irrigation rate is sufficiently high, a shallow mound of water will form. Properly applied, this mound will not exceed about 10 centimeters, but the height will be determined by the discharge rate and piping configuration.

The water will move away from the discharge through the wetland vegetation, which presents an obstruction to flow. This vegetative mat comprises a doubly porous medium, with plant stems and litter forming fine-scale porosity, while hummocks, islands, and channels cause a coarse-scale porosity.

The movement of surface waters through wetlands is characterized by very slow velocities, which result in developing streamline flow. Considering the momentum balance under these conditions, the inertial and acceleration terms are negligible with respect to frictional and gravitational effects. Flow therefore proceeds at the rate at which gravitational forces are just counterbalanced by frictional drag forces.

Although a great deal of work has been done on overland flow (e.g., Woolhiser and Liggett (2)), most have not addressed the problem of point or line water discharges. These geometries are the common approach to wastewater irrigation in wetlands. The functional dependence of water velocity upon depth and gradient in wetlands has been studied by Kadlec, et al. (3). For a point discharge, the material balance for radial flow can be represented by

$$\frac{\partial[\phi_s h]}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}[rh\phi\, v] = p - e - i \qquad [3.3]$$

where r is the radial spatial coordinate, m

ϕ_s is the fraction of wetland available above ground for water storage (storage porosity)

ϕ is the fraction of wetland available for water flow (flow porosity)

v is the water velocity, m/s

p is precipitation, m/s

e is evapotranspiration, m/s

i is the infiltration rate, m/s

t is time, s

It should be noted that there can be a difference between the porosity for water storage and the pore space available for water flow. This is illustrated in Figure 2. Water may soak into hummocks, for example, but they still provide an obstacle to overland flow. The apparent porosities can be expected to vary with water depth, but little quantitative information is

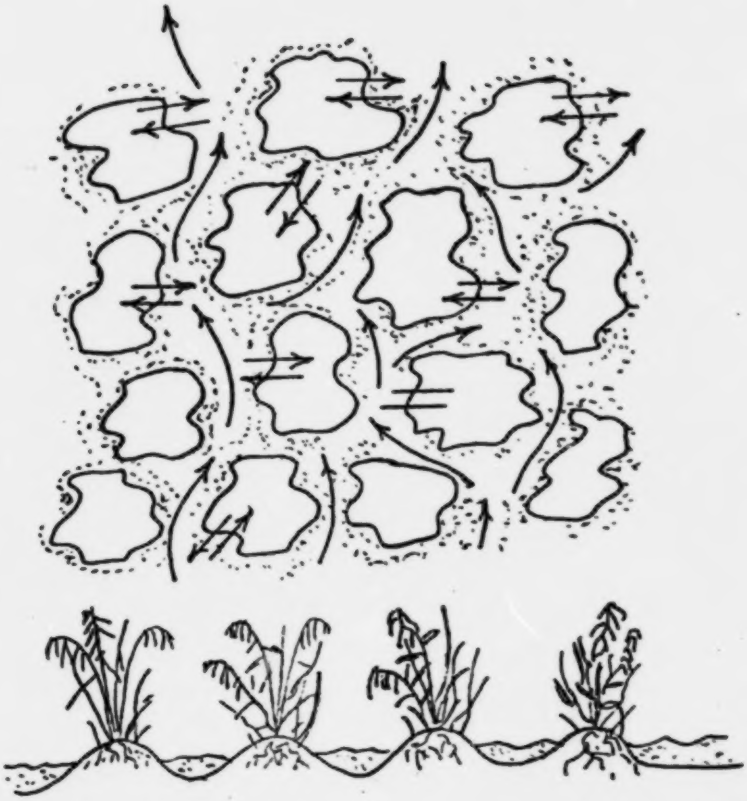


Figure 2. Wetland Surface Water Flow is Impeded by Porous Clumps of Vegetation and Hummocks.

available. Various forms can be assumed for the friction law, to replace ϕv in the Equation 3.3 in terms of h and $\partial h/\partial r$ and thus allow solution (3). These include Darcy's law, which is based upon laminar flow through porous media:

$$\phi v = -k_D \frac{\partial h}{\partial r} \qquad [3.4]$$

where k_D is a constant, m/s.

For turbulent flow in channels, the well-known Manning equation has been verified:

$$\phi v = c_M h^{1/2} \left[\frac{\partial h}{\partial r}\right]^{1/2} \mathrm{sgn}\left(-\frac{\partial h}{\partial r}\right) \qquad [3.5]$$

where c_M is a constant, $m^{1/2}/s$.

If the porosity for flow is assumed to be linearly dependent upon depth, the following friction law results from modification of Darcy's law:

$$\phi v = -c_1 h \frac{\partial h}{\partial r} \qquad [3.6]$$

where c_1 is a constant, s^{-1}.

And similarly if the hydraulic radius is assumed to be the channel depth rather than the typical size of an obstruction (as in Darcy's law) another power law flow expression results:

$$\phi v = -c_2 h^2 \frac{\partial h}{\partial r} \qquad [3.7]$$

where c_2 is a constant, $s^{-1}m^{-1}$.

Other forms of the friction law for overland flow have been presented by Morgali (4) and by Thompson and Roberson (5).

Kadlec, et al. (3), determined solutions to Equation 3.3 using each of the four friction laws shown above. Results were compared with field data for both point and line wastewater discharges. It should be noted that these equations, presented for a point discharge, can easily be converted for the line discharge case, replacing the operator $1/r\ \partial(r)/\partial r$ by $\partial/\partial x$. It was shown that all field data could be reasonably represented by any of these friction laws, with the exception of the Manning equation. Equation 3.7 allowed better fit to certain data sets at the Houghton Lake treatment site. Table 2 shows the characteristic constants determined for overland flow across a sedge meadow in this study.

EVAPOTRANSPIRATION

A number of predictive equations have been developed to allow estimation of evapotranspiration in wetlands. Solar radiation, wind, relative humidity, soil temperature, air temperature, and cover type are all recognized as controlling factors, but the more useful predictive techniques are usually those which use only the meteorological measurements which are commonly available.

TABLE 2. FRICTION LAW CONSTANTS FOR OVERLAND FLOW AT THE HOUGHTON LAKE WASTEWATER TREATMENT SITE

Darcy's Law	$v_s = -k_D \frac{\partial h}{\partial x}$	$k_D = 0.44$ m/s
Linear Porosity	$v_s = -c_1 h \frac{\partial h}{\partial x}$	$c_1 = 6.9\ s^{-1}$
Depth dependent hydraulic radius	$v_s = -c_2 h^2 \frac{\partial h}{\partial x}$	$c_2 = 100\ (m \cdot s)^{-1}$

where $v_s = \phi v$, m/s.

The more popular general methods do not account for variation in transpiration between plant species. Reviews of the major techniques currently in use, have been presented by Chang (6), Knisel (7) and Scheffe (8).

Thornthwaite Method (9)

This procedure is widely used, since it is very simple and generally provides adequate estimates for temperate humid climates. It is empirical, based entirely upon average monthly temperatures and insolation, which are readily available. The approximate nature of this method restricts its usefulness to periods of a month or longer.

Based upon the mean monthly air temperature, values of monthly "heat indices" are obtained (9). Summing the values provide an annual "heat index", I. Daily potential evapotranspiration is now determined, based upon the value of I, and the mean temperature for month (9). These values are finally adjusted, by applying a correction factor for day length, based upon latitude and month (9), and the prediction of potential evapotranspiration is complete. Thornthwaite's method provides no corrections for changes in relative humidity, cloud cover and other solar radiation effects, wind, or cover type. In general, the mathematical form of this model is (7):

$$e = \alpha T_m^{\beta} \qquad [3.8]$$

where T_m is the monthly mean temperature

α and β are constants, empirically determined.

Penman Method (10,11)

These predictions utilize more of the meteorological data which is commonly available from weather stations. Specifically, data on air temperature, duration of bright sunlight, air humidity, and wind speed are included with empirical constants to produce estimates of evapotranspiration from vegetated surfaces. Based in part upon an energy balance, this method involves relatively complicated calculations. Computer programs have been developed to facilitate its use (12, 13). Mathematically the Penman equation can be represented by:

$$e = \frac{\alpha_1(\Delta Q_n + \gamma_1)(P_o - P_a)\ f(v)}{(\Delta + \gamma_1)} \qquad [3.9]$$

$$\text{and} \quad f(v) = 0.35(0.5 + U/100) \qquad [3.10]$$

where Q_n is the net solar radiation, Langleys

P_o is the vapor pressure of water at the mean daily temperature, torr

P_a is the partial pressure of water vapor, torr

U is the wind velocity at a height of 2 meters, miles/day

Δ is the slope of the water vapor pressure curve, at the mean daily temperature

γ_1 is the psychrometer constant maintaining consistent units

α_1 is an empirical constant.

Equation 3.10 expresses the functional dependence of evaporation upon wind speed, with empirically determined constants. Chang (6) and Knisel (7) consider this method to be among the most accurate for estimation of evapotranspiration. Determination of Q_n may pose some difficulty, averaging about 55% of measured incident solar radiation for various cover types (7).

Other Methods

Predictive equations have been devised by many investigators, and have been compared by Stephan and Stewart (14) and elsewhere (6, 8, 13). Scheffe (8) investigated evapotranspiration in wetland cover-types, including sedge, willow, leatherleaf, and cattail. He developed a predictive equation in the form

$$e = \alpha_2 + \beta_2 B + \delta_2 C + \gamma_2 D + \lambda_2 E \ . \qquad [3.11]$$

where B is the incident radiation as measured by pyranograph

C is the air temperature

D is the relative humidity

E is the wind speed

α_2, β_2, δ_2, γ_2, λ_2 are correlation constants.

The results of this work showed that an evapotranspiration equation of this form, based upon wetland data, could provide predictions which were somewhat better than the Penman method. It was discovered however, that the process was largely dominated by radiation effects. Consideration of wind speed was found to be unnecessary, with small effects noted only in the cattail cover-type.

Calculating Evapotranspiration

Methods which require only data readily accessible from weather stations are obviously to be preferred for design predictions. The simplicity of the Thornthwaite method makes it especially attractive for monthly estimates. It has been used very successfully in preparing water budgets for wetlands in areas of temperate climates, but was found quite inaccurate in a humid sub-tropical climate (7). Estimates can often be improved by modification of the model constants based upon evaporation data collected in the cover type of interest.

If daily estimates are required, better accuracy is needed. Therefore, models which include more meteorological data (i.e., Penman, Scheffe or others) are recommended.

RESIDENCE TIME

The rates at which nutrients and other solutes can be removed from the surface waters will dictate the permissible rate of water passage through the system. The period available for treatment is termed the residence time of the system. Wastewater can be exposed to the wetland ecosystem in various ways. If a small area is surrounded by a dike or other enclosure to maintain a captive water pool, wastewater can be treated batchwise (15). The treatment site is flooded, and the water held until the desired effluent quality is achieved. The area can then be drained, releasing the treated water and refilled with a fresh charge. The water residence time for such a process is easily defined. However, as with most large-scale processes, it is often convenient to employ a continuous flow system and an analogous residence time can be defined. The actual residence time θ, for a flow system is

$$\theta = \frac{\text{volume of the surface water}}{\text{volumetric flow rate of surface waters}} \qquad [3.12]$$

In general the volumetric flow will vary from one point in the wetland to another due to rain, evaporation, or stream flows. If these changes are not extreme, an average flow rate will often suffice, otherwise smaller portions of the wetland can be considered separately. For a rectangular wetland with a linear discharge along one side,

$$\theta = \frac{\phi\ hwz}{Q} \qquad [3.13]$$

or

$$\theta = \frac{z}{v} \qquad [3.14]$$

where ϕ is the void fraction of the wetland for water flow

h is the surface water depth, m

w is the width of the flow path, m

z is the distance from the point of wastewater discharge, m

Q is the average surface water flow rate, m^3/s

v is the true velocity of surface waters (average), m/s.

This actual residence time is difficult to obtain accurately, due to the lack of information on wetland void fractions. Small-scale obstructions due to vegetation are a factor in determining the void fraction, but even more difficult to assess are the contributions due to large-scale channelling. In addition the void fraction is undoubtedly a function of water depth. Values of ϕ for the Houghton Lake treatment site have been estimated to be about 0.1 - 0.3 for shallow water sedge meadows, and to approach 1.0 for deep, open water areas.

In absence of better data, some choose to define a superficial velocity, v_s, and superficial residence time, θ_s:

$$v_s \equiv \frac{Q}{hw} \qquad [3.15]$$

$$\theta_s \equiv \frac{hwz}{Q} = \frac{z}{v_s} \qquad [3.16]$$

While lacking intrinsic information about the topography and hydrology of the wetland, the superficial residence time can sometimes be of use in examining data from a single site under varying water depths and flows. At any rate, care must be taken not to confuse the significance and applicability of the actual and superficial values.

SECTION 4

OVERALL ANALYSIS OF OPERATING DATA

One tool for analysis of performance data is correlation. Used extensively by the engineering disciplines, this method allows the determination of controlling factors and the development of predictive equations. In general, unaccounted parameters as well as experimental errors lead to inaccuracies in such predictions. For complex processes, with more than one or two controlling factors, large data sets are needed. If minor but significant factors are neglected, broad bounds on the correlation predictions result.

The prediction of removal rates for wastewater components in wetland systems can be approached from this empirical standpoint. Operating systems, for which performance data are available, can be treated as "black-boxes", each with an average removal rate for each component. By applying only an overall material balance to such a system, the characteristic removal rate can be determined from the inlet and outlet flows. These removal rates might then be correlated in terms of gross system features, such as those listed in Table 3.

CORRELATION OF OPERATING DATA

Data from a number of wetland AWT systems allow calculation of the gross average removal rates of phosphorus and nitrogen. Data reported for the operating sites listed in Table 4 have been presented in various figures which follow.

Correlative efforts have been presented previously by other researchers. Nichols (33) plotted percent removal of nitrogen and phosphorus as a function of loading rate for 7 locations, he found it to result in relatively smooth curve. The importance of system age was difficult to interpret. Other correlations were attempted by Stowell, et al. (34), but the data were rather sparse for marsh/peatland systems.

Plots of nutrient removal rate versus system age do not, on their own, establish any clear trend as can be seen in Figures 3 and 4. Figure 5 and Figure 6 show the average removal rate versus input concentration for phosphorus and nitrogen, respectively. While precise relations cannot be established using these data from diverse systems, a trend of increasing removal rate with increasing nutrient concentration is suggested. Plots of nutrient removal rate versus nutrient loading rates, are shown in Figures 7 and 8. These define the operating limits which are observed on existing systems, regardless of hydrology, cover-type, or climatic considerations. In Figure 7 the phosphorus removal rate is seen to fall within a broad band. Older and/

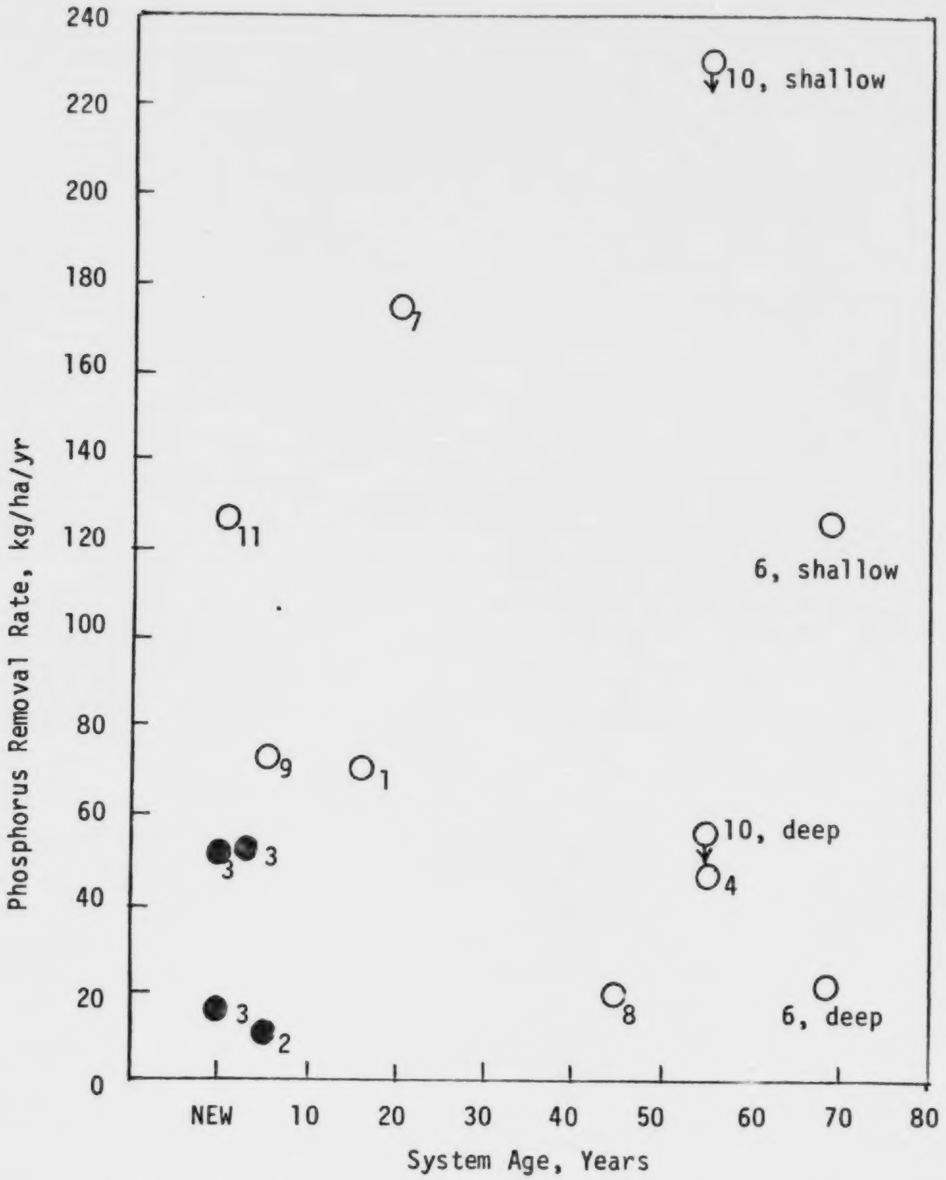


Figure 3. Effect of System Age on Phosphorus Removal Rate. (See Table 4 for Site Identification Numbers)

○↓ Rate Based Only on Growing Season, thus Likely High Compared to Annual Average.

○ Total Phosphorus ● Total Dissolved Phosphorus

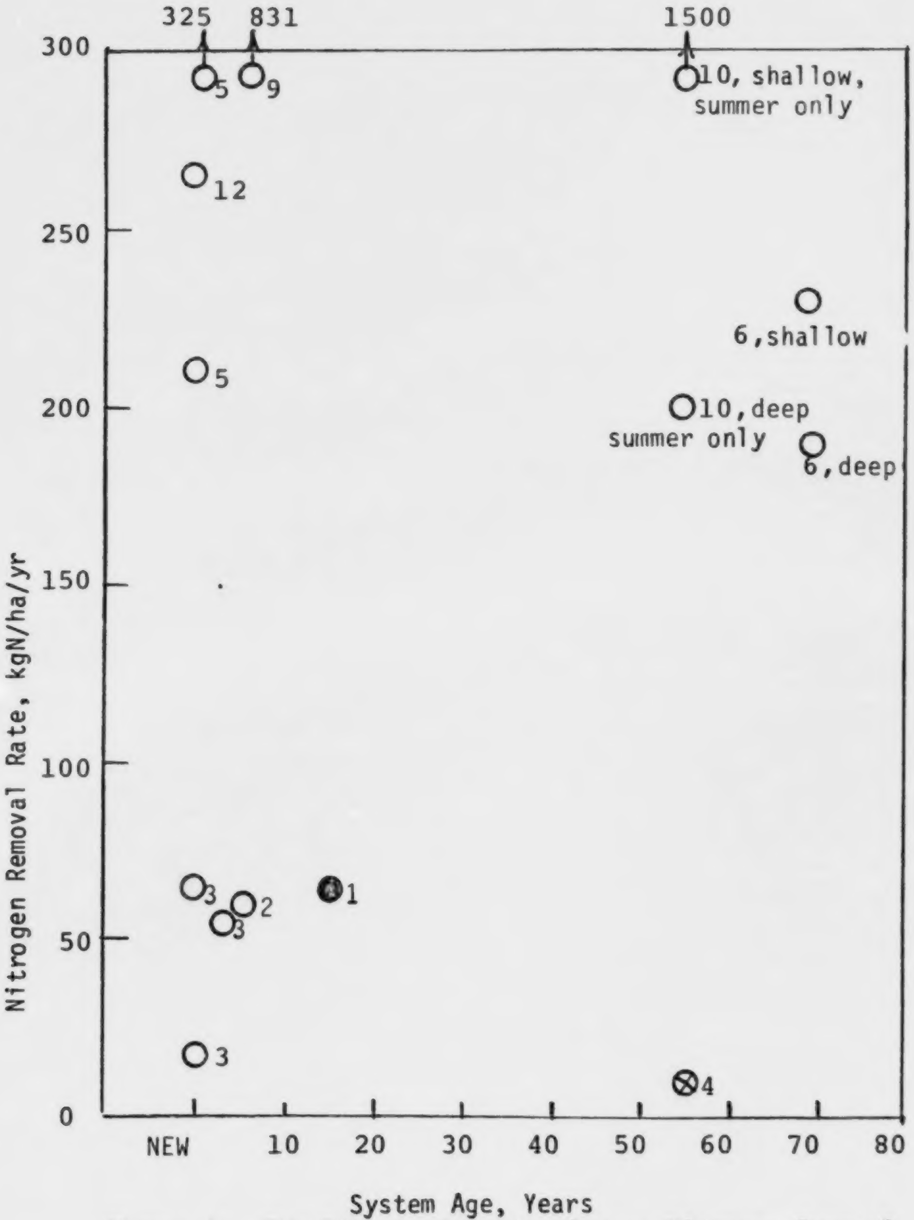


Figure 4. The Effect of System Age on Nitrogen Removal Rate. (See Table 4 for Site Identification Numbers.)

○ $NO_3^- + NO_2^- + NH_4^+$ ⊗ NO_3^- only ● NH_4^+ only

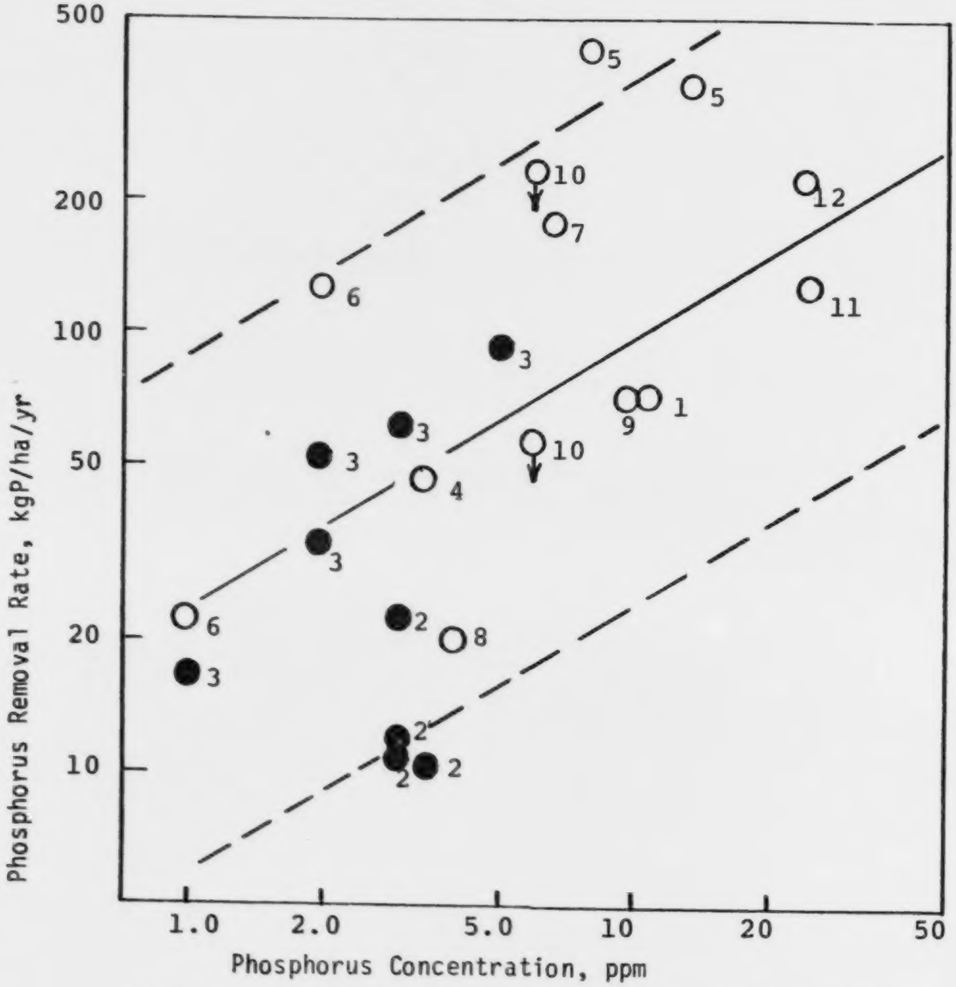


Figure 5. The Effect of Concentration on the Phosphorus Removal Rate. (See Table 4 for Site Identification Numbers.)

○↓ Rate based on only growing season, thus is likely high compared to annual average.

○ Total phosphorus ● Total dissolved phosphorus

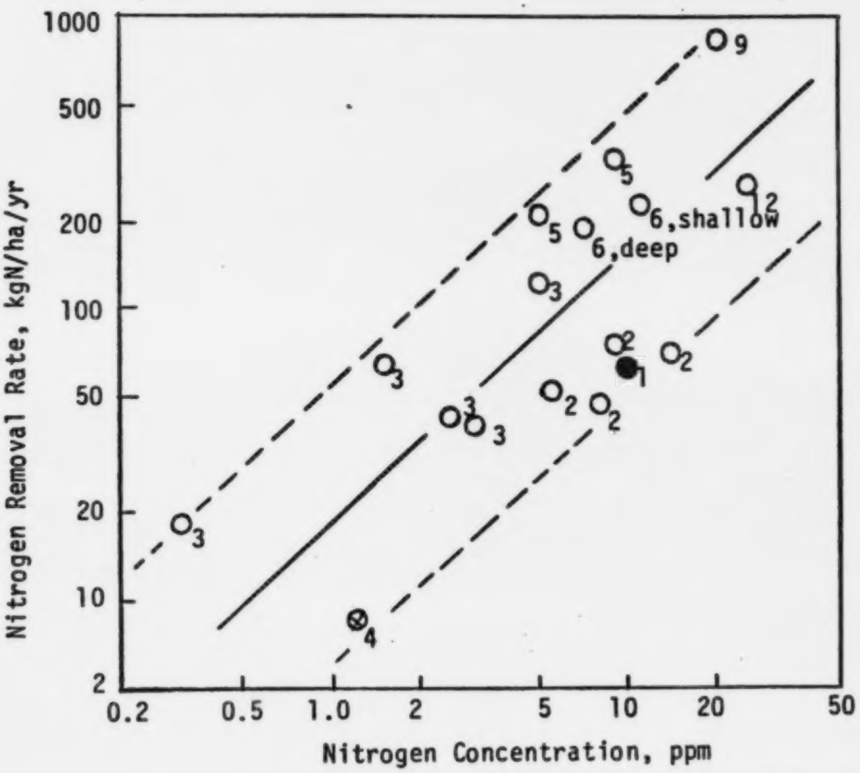


Figure 6. The Effect of Concentration on the Nitrogen Removal Rate. (See Table 4 for Site Identification Numbers)

○ $NO_3^- + NO_2^- + NH_4^+$ ● NH_4^+ only

⊗ NO_3^- only

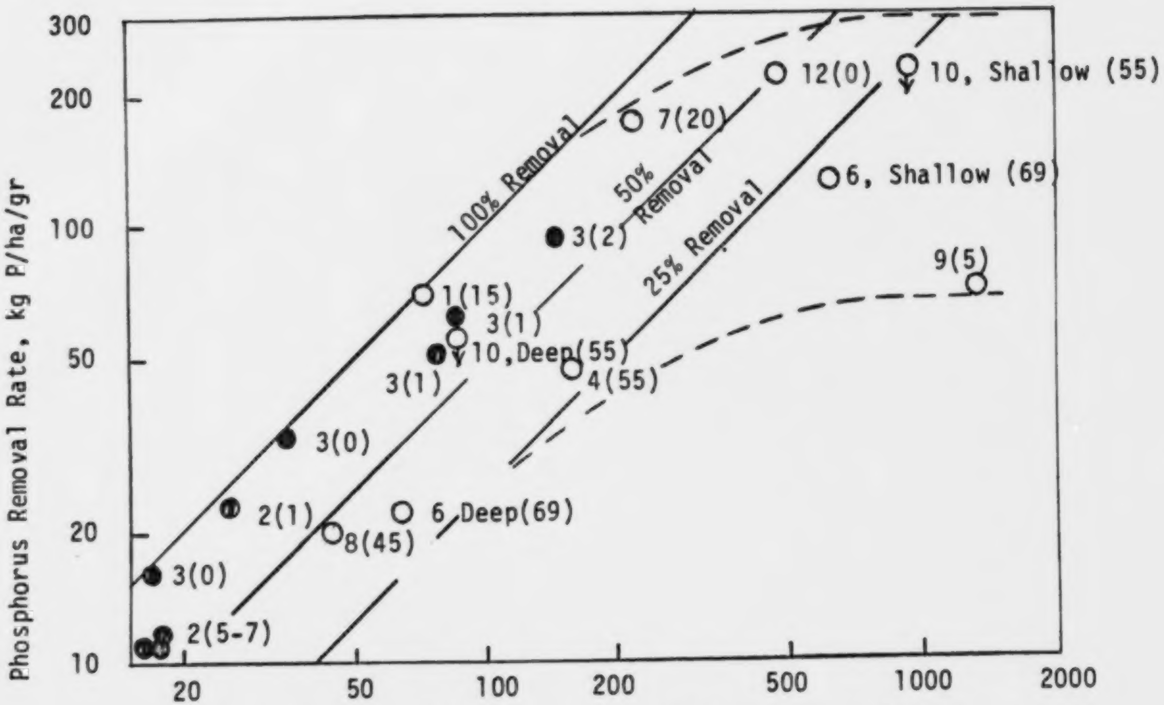


Figure 7. Effect of Phosphorus Loading Upon Removal Rate. (See Table 4 for Site Identification Numbers)

● Total Dissolved Phosphorus

○ Total Phosphorus

⚲ Rate Based on Growing Season, Thus is Likely High Relative to Annual Average

( ) Denoted Approx. Age of Site

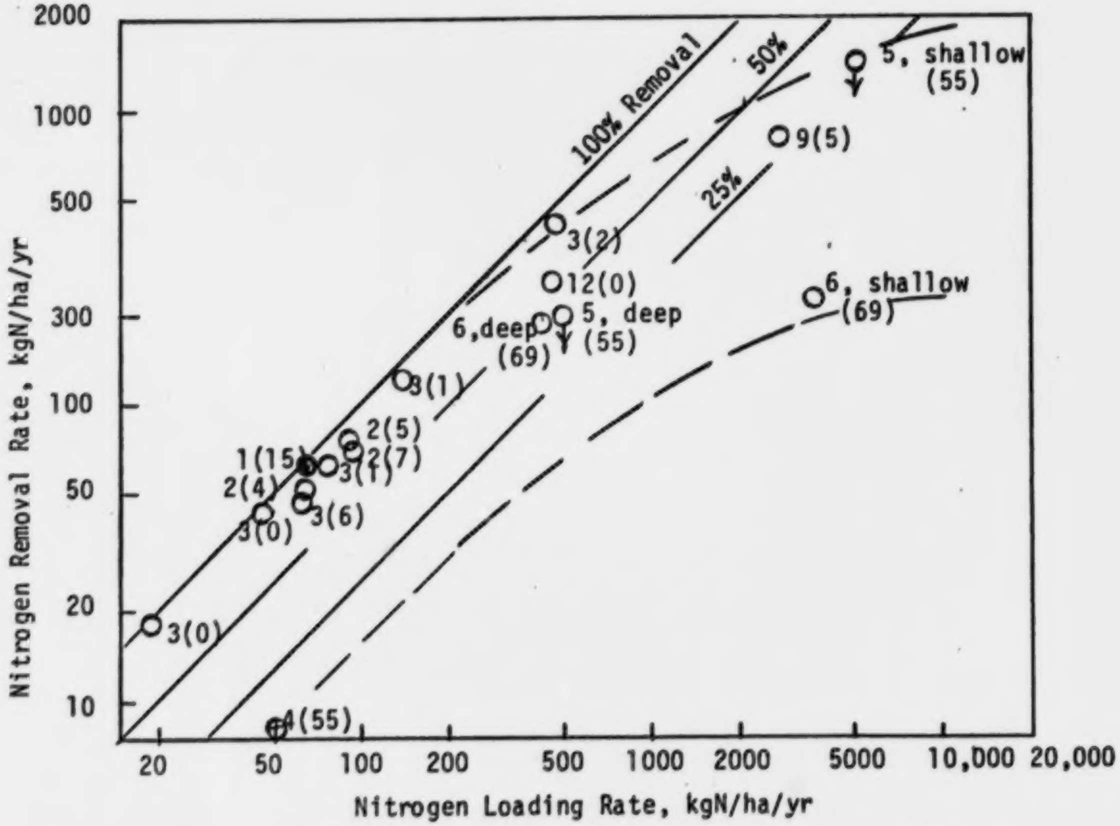


Figure 8. The Effect of Nitrogen Loading Upon Removal Rate. (See Table 4 for site identification numbers.)

○ $NO_3^= + NO_2^- + NH_4^+$ ⊕ $NO_3^=$ only ● NH_4^+ only

Rate based upon growing season only, thus likely high relative to annual average. () Denotes approx. age of system or deeper systems appear to be displaced in this band in the direction of poorer removal. Figure 8, displaying the nitrogen loading/removal relationship, shows a similar band of performance.

INTERPRETATION OF OPERATING DATA

The approximate bounds observed span the range in current wetland AWT performance, from the best to the worst. Since the selection of some of these sites was based entirely upon proximity, and management techniques based on convenience, it is reasonable to expect that many of these systems operate with depths, flow patterns, and other factors which are unfavorable. Nutrient removal per unit area may be better at some locations than indicated, because the actual effective/affected area may be considerably less than the estimated wetland size. Preliminary design judgements can be made based upon the bounds and trends observed in the preceeding figures. Due to the uncertainty in these data, conservative choices may result in systems which are reliable, but could be far from optimal. Conversely, if hydrology, wetland features and ageing are not properly included in the design analysis, there is little assurance that a new system will give long service within these bounds.

Precise relationships between system performance and controlling factors are impossible to ascertain from these data, but general trends and bounds on operations can be observed. The apparent "scatter" in the following figures are the result of unaccounted factors in site hydrology and discharge history. With the exception of the systems at Houghton Lake and Bellaire, Michigan, these data are the result of short studies (generally 1-2 years or less). The system ages range from new to nearly 70 years.

Important features of the hydrology at many treatment sites have not been determined. The water budget, although critical, can be difficult to determine accurately and even estimates are sometimes not available. In some cases, nutrient retention is calculated based solely on the inlet and outlet concentrations without water budget corrections due to rain, evapotranspiration or other water flows. The water depth and inventory within the wetland vary from month to month, and this information, needed to allow residence times to be calculated, is seldom reported. The residence time, and even the calculated nutrient retention rates, are subject to further uncertainty due to channelization and difficulties in the determination of the actual affected wetland surface area. Lack of detailed hydrological information of this type hinders data correlation from diverse systems.

Finally, most operating data represent but a single year at sites with differing ages. The separate effects of ageing and of altered loading rates cannot be reliably assessed from these present data. The typical effluent from a municipal treatment plant changes progressively from year to year, usually increasing both in volume and in nutrient concentration. If discharging to a wetland for AWT, alteration of the ecosystem may occur over the same time period, thus altering its ability to treat wastewater. In order to adequately de-couple the effects of these concurrent changes a larger data base will be required.

TABLE 3. POTENTIAL FACTORS AFFECTING THE PERFORMANCE OF WETLAND TREATMENT SYSTEMS

	Probable Effects	Problems in Data Interpretation
Water depth	*Affects residence time and flow characteristics. *Encourages some species/processes while hampering others.	*Controlled experiments have not been completed. *Insufficient data, often lacking from operation reports.
Residence time	*Long residence times should improve wastewater treatment, but may not, if due to increased depths.	*Difficult to determine accurately due to channelization. *Few data available. Controlled experiments have not been completed.
Nutrient Concentrations & Loading Rates	*While removal rates should increase with concentration, each system will likely exhibit rate limits.	*Data are influenced by other factors which have not been accounted for.
Cover-Type & Climatic Conditions	*Largely unknown, but high productivity should enhance nutrient removal.	*Insufficient data.
Type of Substrate/Soil	*Largely unknown.	*Insufficient data.
Discharge Schedule	*Unknown.	*Insufficient data.
System Age	*Nutrient retention rates may change with time due to saturation phenomena and to changes in the ecosystem.	*Data are influenced by other factors which have not been accounted for. *Site histories for older systems are often quite sketchy.

TABLE 4. OPERATING SYSTEMS REPORTING RATE DATA

No.	Site	Data Sources
1	Hay River	Hartland-Rowe and Wright (16)
2	Bellaire	Kadlec (17), (18), (19); Kadlec and Tilton (20)
3	Houghton Lake	Kadlec and Hammer (21), (22); Kadlec (17); Kadlec, *et al*. (23)
4	Brillion	Spangler, *et al*. (24), (25)
5	Clermont	Zoltek, Bayley, *et al*. (26)
6	Great Meadows	Yonika, Lowry, *et al*. (27)
7	Wildwood	Boyt, Bayley and Zoltek (28)
8	Waldo	Nessel and Bayley (29)
9	Mt. View	Demgen (30)
10	Cootes Paradise	Semkin, et al. (31)
11	Seymour	Spangler, *et al*. (25)
12	EBC System	Nute and Nute (32)

SECTION 5

CONCEPTUAL MODEL: THE WETLAND TREATMENT PROCESS

A SIMPLIFIED COMPARTMENTAL MODEL

In order to develop improved design techniques for AWT systems, it is necessary to consider individual phenomena and processes within the wetland. A larger body of reliable data is available on the function of wetland subsystems than on the performance of the wetland as a whole. By developing and combining relatively simple models of significant on-going processes, it is possible to obtain further insight into the overall interactions between the wetland and applied wastewater. This procedure allows the synthesis of a conceptual model, which when represented in mathematical terms can be used to evaluate a new design.

Wetland modelling has frequently employed the concept of "compartments". The compartments are physical entities (soil, plants, water, etc.), between which exchanges of nutrients or other substances occur. These transfer steps are complex and many are poorly understood. Figure 9 depicts some of the major interactions. This approach has been used by Parker (35) and by Gupta (36) in computer simulations of a wetland ecosystem's response to wastewater additions.

To facilitate the use of a model over long periods of time (e.g., 20 to 50 years) a simpler, specialized structure is desirable. Such a structure is described in Figure 10. This arrangement has been chosen for its simplicity and its usefulness in characterizing the wastewater treatment process. All transfers between the surface waters and the stationary ecosystem are taken as the annual net accumulation in each compartment. In this way, cycling of nutrients and other materials on seasonal basis need not complicate the model.

THE DELIVERY/CONSUMPTION PROCESS

The removal of a wastewater component, such as phosphorus, from the surface water sheet can be envisioned as a two-step process. First, phosphorus must be delivered to some consuming entity or compartment within the stationary ecosystem. For solutes, this is accomplished by bulk water flow, by diffusion and by convective mass transfer. For suspended material the nature of the water flow and settling behavior will determine the delivery rate. Once delivered, phosphorus must then be consumed and incorporated into the stationary ecosystem, this step also proceeds at a finite rate. Major consumption mechanisms for nutrients and heavy metals are summarized in Table 5. In this case, consumption is defined as the net removal of wastewater

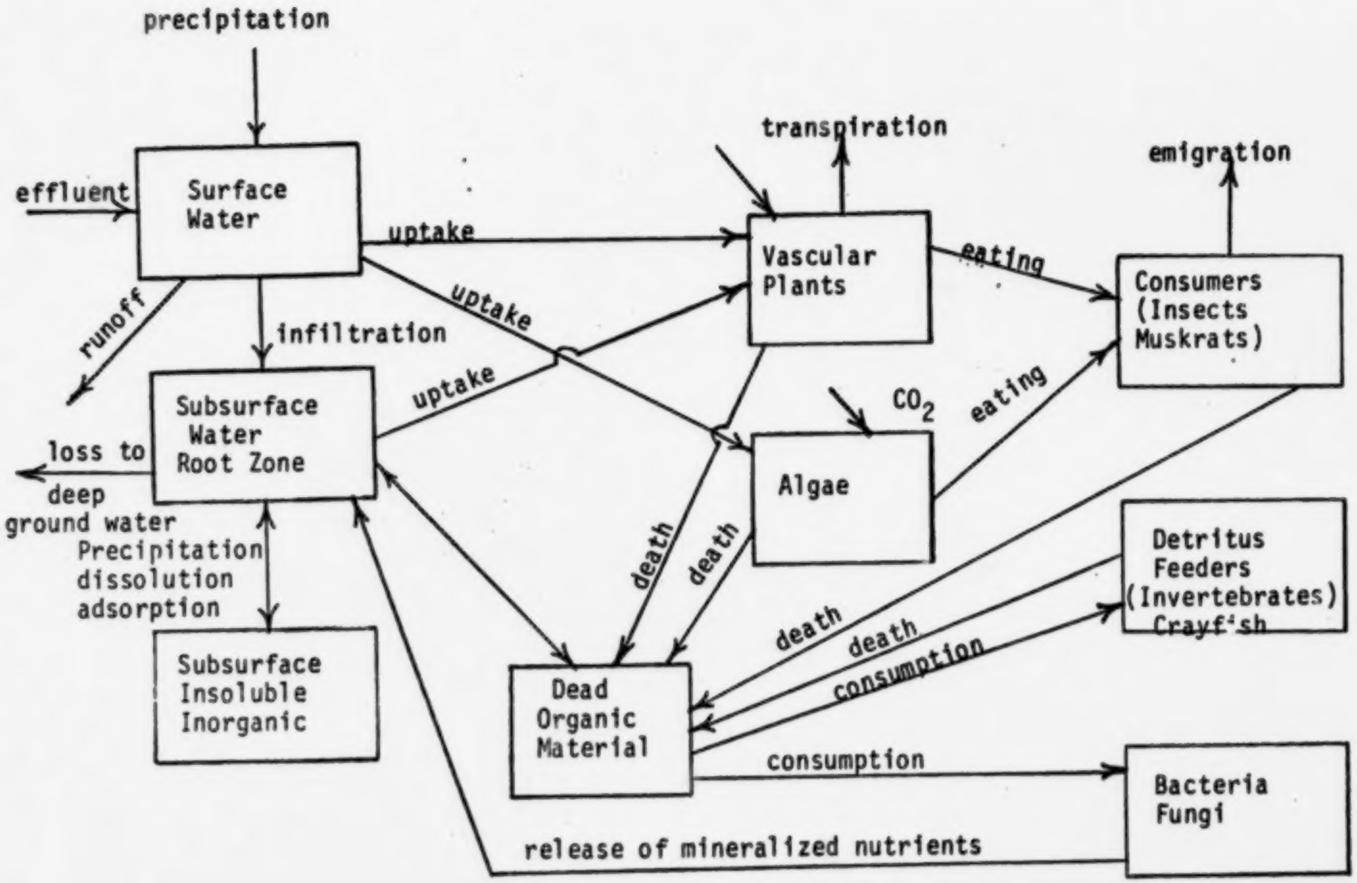

precipitation
effluent
Surface Water
runoff
infiltration
uptake
uptake
uptake
Subsurface Water Root Zone
loss to deep ground water
Precipitation dissolution adsorption
Subsurface Insoluble Inorganic
transpiration
Vascular Plants
eating
emigration
Consumers (Insects Muskrats)
CO2
Algae
eating
death
death
Dead Organic Material
death
death
consumption
Detritus Feeders (Invertebrates) Crayfish
consumption
Bacteria Fungi
release of mineralized nutrients

Figure 9. Water and Nutrients are Exchanged Between Wetland Compartments.

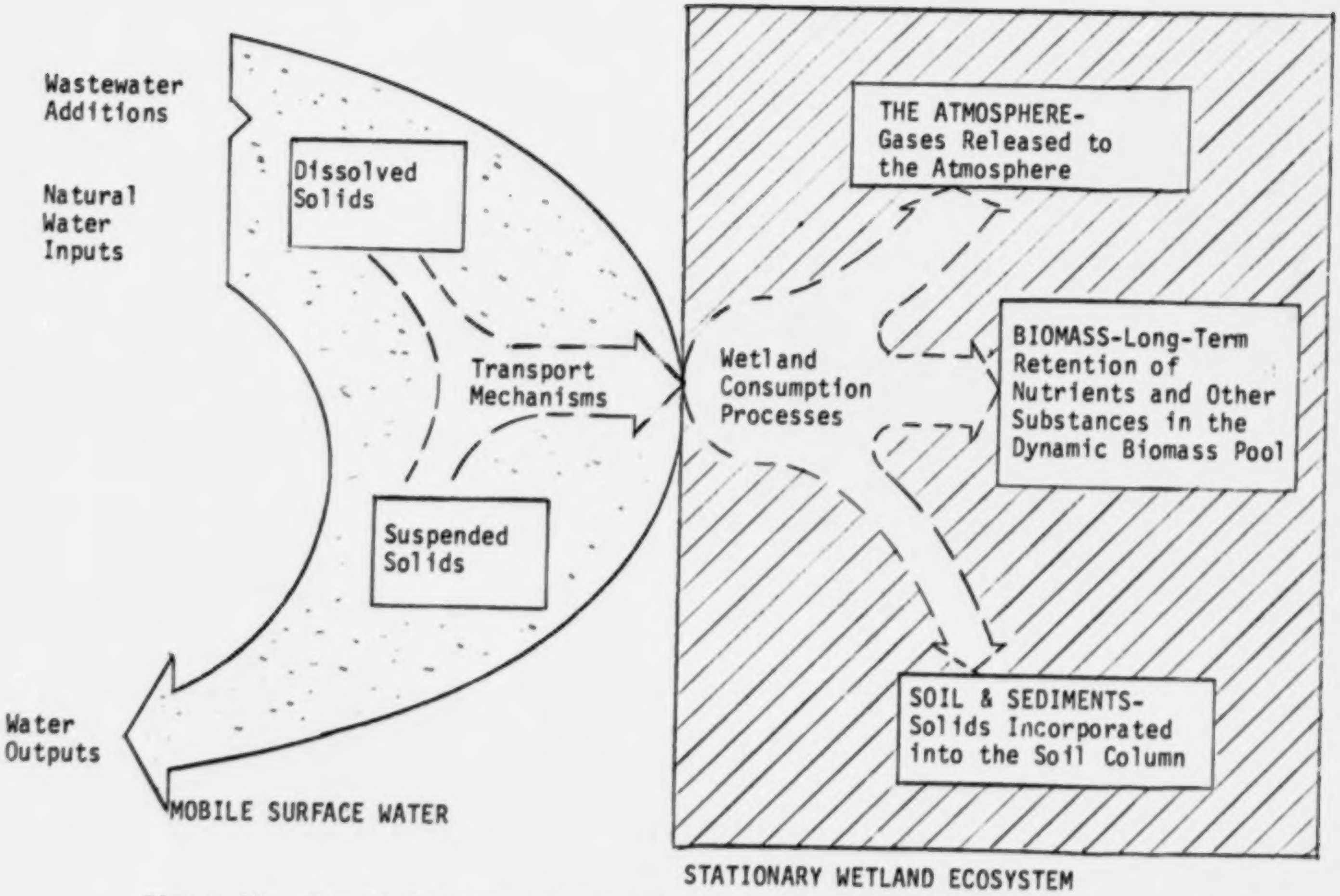

Wastewater
Additions
Natural
Water
Inputs
Dissolved
Solids
Transport
Mechanisms
Suspended
Solids
Water
Outputs
MOBILE SURFACE WATER
Wetland
Consumption
Processes
THE ATMOSPHERE-
Gases Released to
the Atmosphere
BIOMASS-Long-Term
Retention of
Nutrients and Other
Substances in the
Dynamic Biomass Pool
SOIL & SEDIMENTS-
Solids Incorporated
into the Soil Column
STATIONARY WETLAND ECOSYSTEM

Figure 10. Simplified Compartmental Model for Use in Wetland Treatment System Design.

components from surface waters, after accounting for seasonal cycles. If the potential delivery or consumption rates differ greatly, the slower step will dictate the overall removal rate.

TABLE 5. MAJOR CONSUMPTION MECHANISMS FOR NUTRIENTS AND HEAVY METALS IN WETLAND TREATMENT SYSTEMS

1. Biomass expansion
2. Adsorption
3. Soil building
4. Microbial activity

The delivery rate depends largely upon characteristics of the surface water sheet, such as depth, flow rate, and component concentrations. Thus, given similar conditions, the potential transport rate of material to the stationary ecosystem should not vary drastically from year to year. The consumption mechanisms however, such as adsorption and the production of new biomass, can exhibit saturation phenomena. Therefore the rate of the consumption step may slow with time for wetland areas exposed to wastewater.

In order to determine the peak rates for these delivery and consumption steps, the nature of the mechanisms involved must be examined. The subsequent sections discuss the major processes which determine the removal rate of wastewater components, and sources of rate data.

TRANSPORT OF DISSOLVED SOLIDS

In new wetland areas, where no saturation with nutrients or heavy metals has occurred, removal rates for wastewater components appear to be controlled by the mass transfer rate through the surface waters (37). This transport, or delivery phenomenon can be described by the following expression:

$$N_A = k_A (C_A - C_{AS}) \qquad [5.1]$$

where N_A is the mass flux of component A, kg A/m^2/s

C_A is the concentration of A in the bulk flow of surface waters, kg A/m^3

C_{AS} is the concentration of A at the site of consumption kg A/m^3

k_A is the mass transfer coefficient for A through surface water, m/sec

If C_{AS} is assumed to be negligible with respect to C_A, the transport rate of A through water is given by:

$$N_A = k\, C_A \qquad [5.2]$$

where k is the first-order model coefficient, m/sec

This general rate law can represent not only mass transfer, but also any irreversible first-order process, such as a chemical reaction. The assumption of negligible C_{AS} is generally valid when the surface water concentrations of the component of interest are much higher than the natural background levels in the wetland.

Combining Equation 5.2 with a material balance for A on the mobile subsystem the following time-concentration or distance-concentration relationships result. For simplicity water is assumed to be conserved throughout (i.e., no evaporation or rain).

For the linear discharge system (such as a gated irrigation pipe), the downgradient concentration of component A can be given by Equation 5.3. A similar expression also describes the radial variation in concentration for a point discharge system.

$$\ln \frac{C_A}{C_{AO}} = -\frac{kz}{vh} \qquad [5.3]$$

where C_{AO} is the concentration of A at the point of wastewater discharge, kg A/m^3

z is the distance from the discharge, m

v is the actual water velocity, m/s

h is the water depth, m

Flow is considered to be steady and continuous, and depth has been assumed constant. In the linear discharge system, water velocity can also be considered constant.

Figure 11 shows the phosphorus profiles obtained from a large-scale experiment over a three year period. Wastewater was added at a rate of 10,000 m^3/day over a 1000 m line to a 7 km^2 wetland. It can be seen that a zone of saturation expands with time, and that it is followed by a zone of decreasing nutrient concentration. The phosphorus level is seen to approach background values at a decreasing rate. Nitrogen removal curves exhibit similar behavior (22). This zone of decreasing concentration does appear to follow the first-order model proposed in Equation 5.3, since a plot of field data for ln (C_A/C_{AO}) versus z produces a straight line with slope -k/vh. Figure 12 shows such plots for phosphorus and nitrogen. The linearity of these plots support the hypothesis that nutrient removal is mass transfer

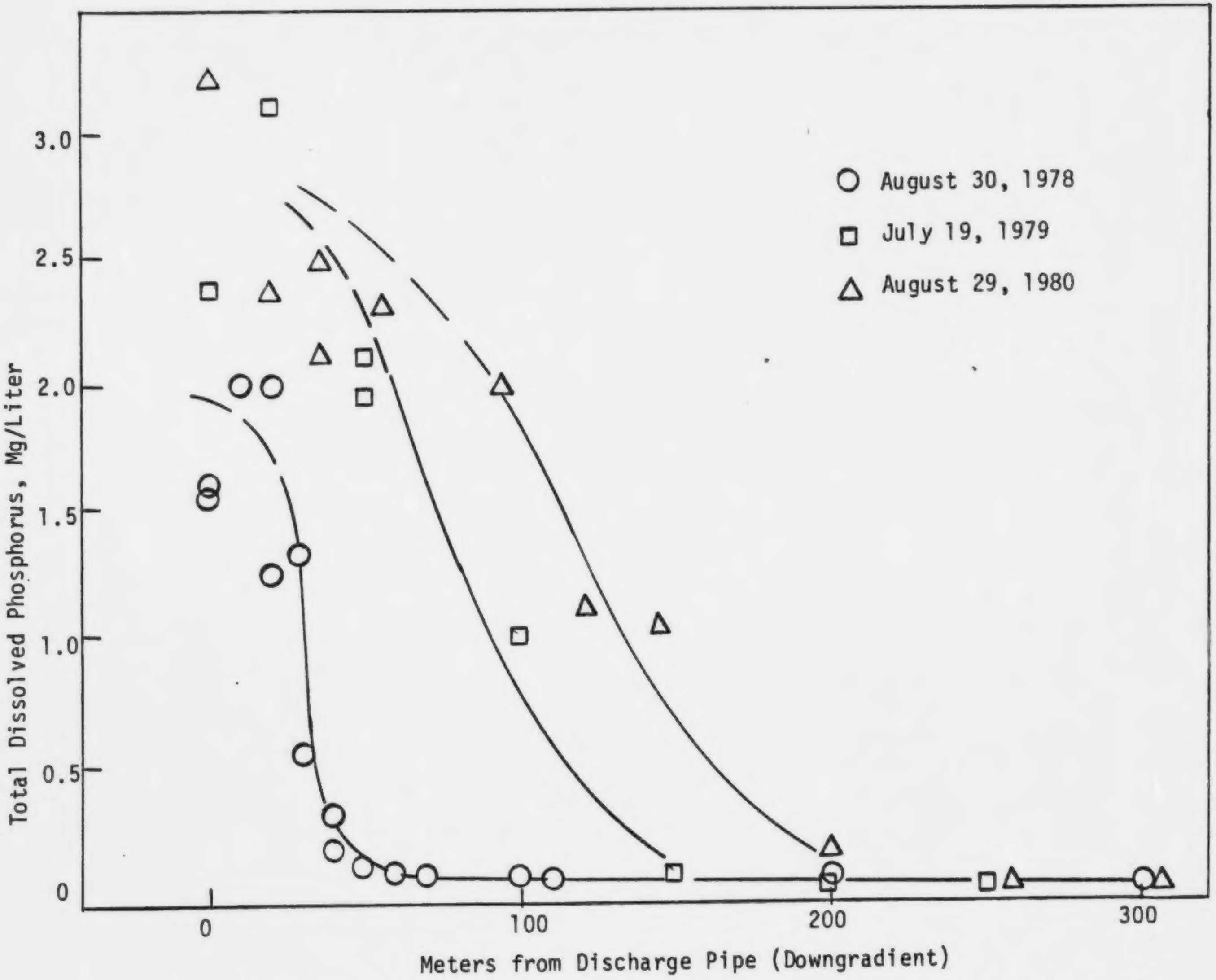


Figure 11. Phosphorus Profiles in Surface Water at the Houghton Lake Treatment Site. Data from Sedge-Willow and Leatherleaf Cover Type Areas.

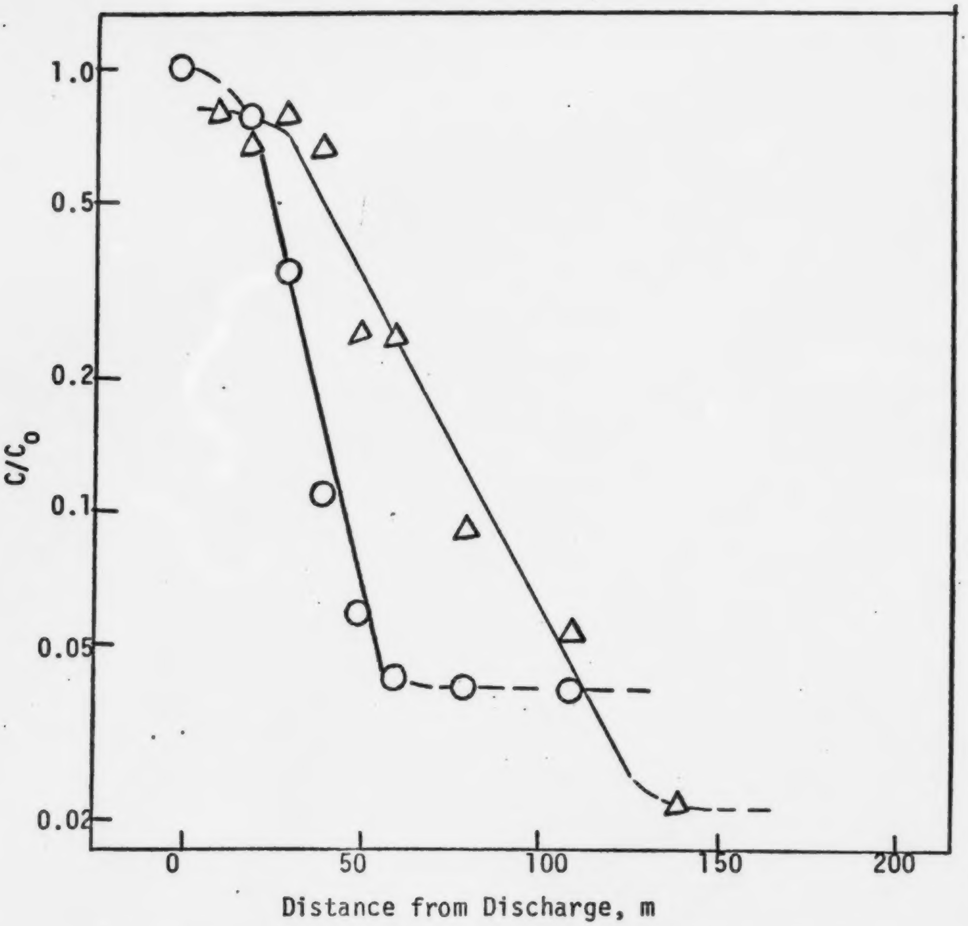


Figure 12. First-Order Model Fit for Uptake of Phosphorus & Nitrogen.

Data from Full-Scale System Operations at Houghton Lake, Mich. Sedge-Willow Cover Type August 1978.

○ Total Dissolved Phosphorus △ Ammonium-N controlled. Similar results have been reported for point discharge systems as shown in Figure 13, and also from laboratory studies (37).

Batch operations can be described in an analogous manner, combining Equation 5.2 with a material balance to obtain the result:

$$\ln \frac{C_A}{C_{AO}} = \frac{-k\,\theta}{h} \qquad [5.4]$$

where θ is the batch holding time, s.

Flow systems can also be represented by this equation, identifying θ as the residence time. Batch data for phosphorus removal have been plotted in Figure 14, and they exhibit the same first-order rate dependence observed in flow systems. Table 6 presents values of k computed for initial operations of the batch system at Humboldt, Saskatchewan.

TABLE 6. FIRST-ORDER CONSTANTS FROM BATCH OPERATIONS AT HUMBOLDT, SASKATCHEWAN - FROM LAKSHMAN (15)

All entires are k (cm/sec) x 10^5

	Month	Initial Depth	Total Phosphorus	B.O.D.	Total Nitrogen
Lined Lagoon	Sept	42 cm	8.4	13	6.7
	Oct	64	2.4	5.7	<<1.0
Ditch #1	Sept	22	3.5	7.1	4.4
	Oct	33	3.8	6.6	2.5
Ditch #2	Sept	21	4.8	5.6	0.67
	Oct	33	7.6	7.6	3.3
Ditch #3	Sept	27	6.2	7.2	1.2
	Oct	33	7.6	6.6	3.1
Unlined Lagoon	Sept	27	5.4	7.2	3.6
	Oct	33	5.3	6.6	1.7
		Mean	5.5	7.3	2.7
		Std. Deviation	2.0	2.1	2.0

Wetland Mass Transfer Coefficients

Well-established mass transfer correlations are available for fully developed flow in simple geometries. Such predictive tools might be expected to describe the behavior of nutrient removal in wetland treatment systems,

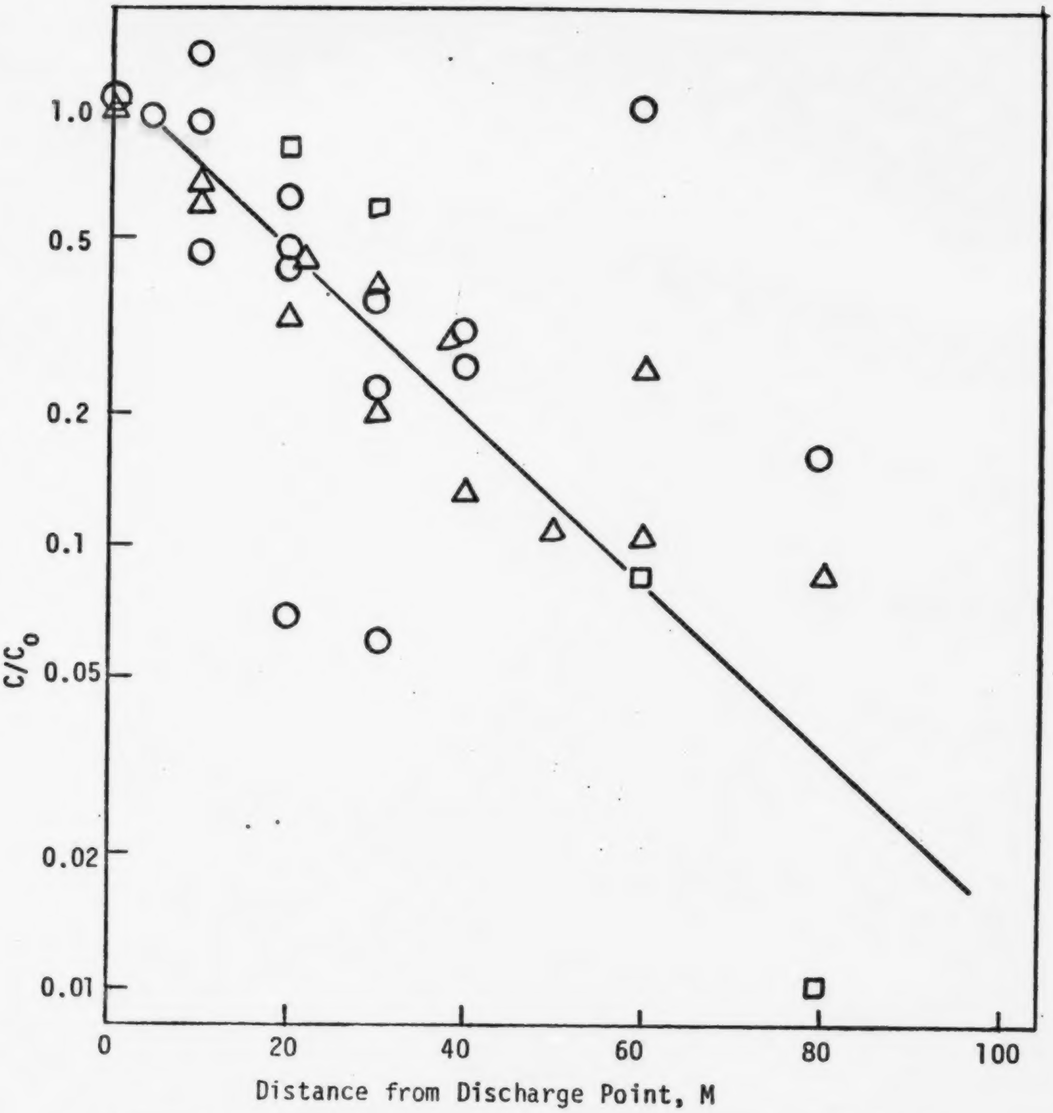


Figure 13. Ion Uptake in Point Discharge Experiment at the Houghton Lake Treatment Site (1977 Pilot).

□ Total Dissolved Phosphorus ○ Nitrate △ pH

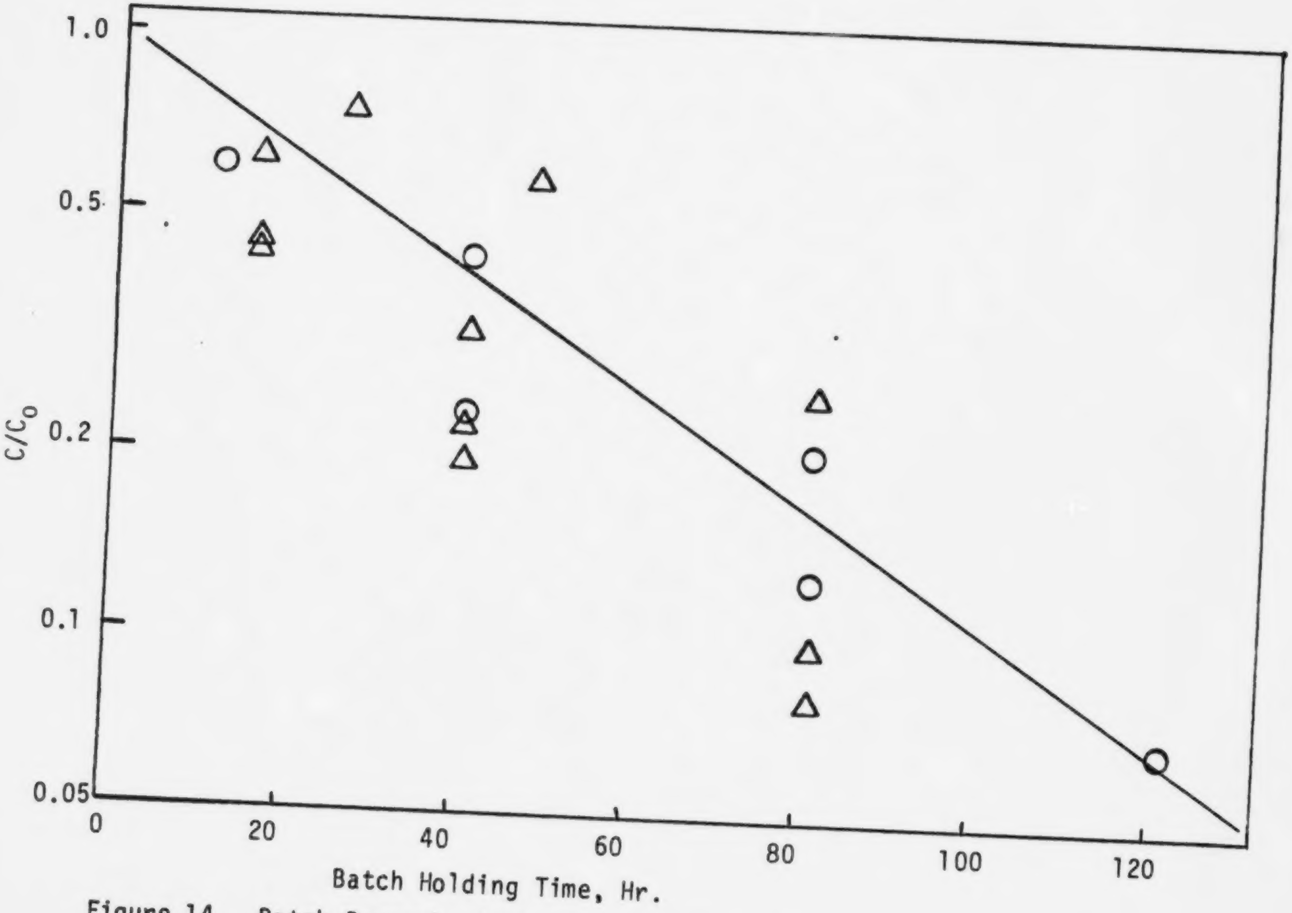


Figure 14. Batch Removal of Phosphorus from Wastewater at Humboldt, Sask. Depths and Substrate Differs for Phosphorus Removal for Various Batch Cells; Data from Lakshman (15).

○ September

△ October

presuming that mass transfer is indeed the controlling rate step. For both laminar and turbulent flow, with developed velocity profiles, the mass transfer coefficient not only depends upon the velocity and characteristic dimension of the system (Reynold's number), but for short channels, the development of a concentration boundary layer makes the channel length also a significant factor.

Bennett and Myers (38) give the following correlation for mass transport, for laminar flow of a fluid over a flat surface:

$$Sh_m = 0.66 \, (Re_L)^{1/2} \, Sc^{1/3} \qquad [5.5]$$

where Sh_m is the mean Sherwood number for the entire surface, kL/D_A

Re_L is the length Reynold's number, $\rho vL/\mu$

Sc is the Schmidt number for the fluid, $\mu/\rho D_A$

k is the mass transfer coefficient for the solute of interest, cm/s

L is the length of the flow path, cm

D_A is the solute diffusivity, cm^2/s

ρ is the fluid density, gm/cm^3

μ is the fluid viscosity

v is the actual fluid velocity, cm/s

It is convenient to express the mass transfer coefficient in terms of a depth Reynold's number, $Re_h = \rho vh/\mu$, where h is the surface water depth. Using a typical solute diffusivity of 1.0×10^{-5} cm^2/s and the physical properties of water, Equation 5.5 can be recast in dimensional form,

for laminar flow:

$$k = 6.6 \times 10^{-5} \, \frac{(Re_h)^{1/2}}{(hL)^{1/2}} \qquad [5.6]$$

$$k = 6.6 \times 10^{-4} \, \left(\frac{v}{L}\right)^{1/2} \qquad [5.7]$$

At higher Reynold's numbers, Re_h greater than about 2000 on a smooth plate, turbulent flow will occur. Mass transport in the turbulent regime for a flat surface has been also described (38), for turbulent flow:

$$Sh_L = 0.0365\,(Re_L)^{0.80}\,Sc^{0.43} \qquad [5.8]$$

Making the same simplifying substitutions as before the dimensional equation is obtained,

$$k = 7.12 \times 10^{-6}\,\frac{(Re_h)^{0.80}}{(L^{0.2}\,h^{0.8})} \qquad [5.9]$$

$$k = 2.83 \times 10^{-4}\,\frac{v^{0.8}}{L^{0.2}} \qquad [5.10]$$

Figure 15 shows a plot of Equations 5.6 and 5.9 for typical conditions encountered in a wetland with primarily sedge and willow vegetation. Natural channelization has been assumed to occur, with open water runs varying from approximately one to ten meters long. Water depth has been assumed to be on the order of 15 cm. The values predicted by these correlations fall within the bands indicated.

Semi-log plots have been prepared for field and laboratory data (similar to those shown in Figure 12), and mass transfer coefficients calculated. Data for water depths and velocities were employed wherever possible, or these parameters were estimated. The experimental results are shown on Figure 15. The mass transfer coefficients are higher than predicted by the generalized correlations. This feature can be explained by consideration of so called "entrance effects". Most often, the nature of channelization and the flow rates of surface water in the wetland do not result in fully-developed velocity profiles. Average transport rates are therefore higher, due to the reduced resistance resulting from the absence of a complete momentun boundary layer.

The experimental data for the mass transfer coefficient at the Houghton Lake site might be represented by

$$k = a\,Re_h \qquad [5.11]$$

where a is a constant, cm/s.

If a hydrological model of overland flow at this site is assumed to be of the form (constant gradient):

$$v = b\,h^{\beta} \qquad [5.12]$$

where b and β are constants

then the velocity dependence of the mass transfer coefficient can be determined. For the case $\beta = 2$,

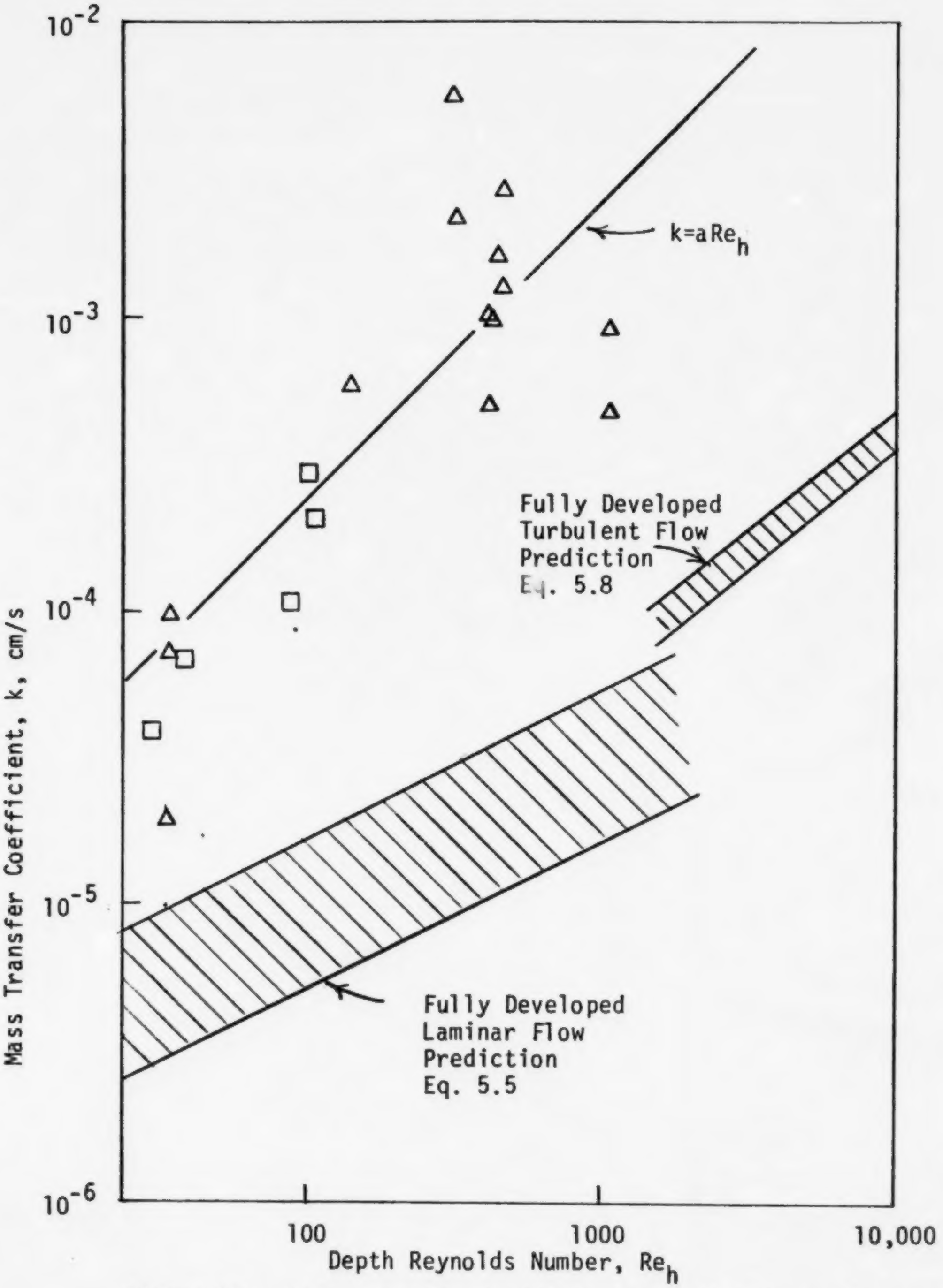


Figure 15. Mass Transfer Coefficients-Predicted and Observed.

△ Field Data, Houghton Lake Treatment Site

□ Laboratory Data, Kadlec & Hammer

$$k = c\,v^{3/2} \qquad [5.13]$$

where c is a constant, $s^{1/2}/m^{1/2}$

A plot of the experimental mass transfer data versus water velocity is shown in Figure 16. A line with slope 3/2, corresponding to Equation 5.13, has been drawn through these data. Other hydrological models will result in other slopes on this plot.

TRANSPORT AND REMOVAL OF SUSPENDED SOLIDS

The suspended solids content of wastewater or of surface waters is in itself an important water quality parameter. The movement of suspended solids in a wetland system also constitutes a mechanism for transport of phosphorus, nitrogen, and other substances. The importance and nature of such solids in wetland wastewater treatment systems has been largely unidentified.

Suspended solids found in wetland surface waters may come from varied sources: incoming wastewater, stream-borne silt and inorganics, detritus from algae and vascular plants, and in the literal sense, many mobile organisms, particularly invertebrates. Slow surface water velocities and long residence times promote the retention of solids. Vegetation causes surface waters to follow a tortuous path, around and through innumerable obstacles which provide sites where suspended particles may impact, lose momentum settle.

The suspended material in a wetland may be but a small fraction of the accumulated "suspendable" pool. Preliminary measurements at the Houghton Lake treatment site indicate that this potential pool represents on the order of several grams of solids per liter of surface water, and these solids possess a relatively high nitrogen and phosphorus content (39). Some of these solids are of nearly neutral bouyancy, exhibiting resuspension in a still water column due to temperature induced density changes. It is not known how mobile these suspendable sediments are under varied hydrological conditions, and seasonal effects have not been elucidated. These and related topics are the subject of ongoing research at the Houghton Lake site.

The resuspension of sediments has received considerable attention in the literature (40, 41, 42), but studies are generally confined to beds of non-cohesive granular solids. Shields (43) defined a dimensionless stress, by forming a ratio between the shear stress applied to the sediment bed, τ, and the weight of the top layer of submerged solid grains per unit area,

$$S = \frac{\tau}{(\rho_s - \rho_w)gD} \qquad [5.14]$$

where S is the dimensionless stress

τ is the fluid shear stress applied to the surface of the sediment bed, dyne/cm^2

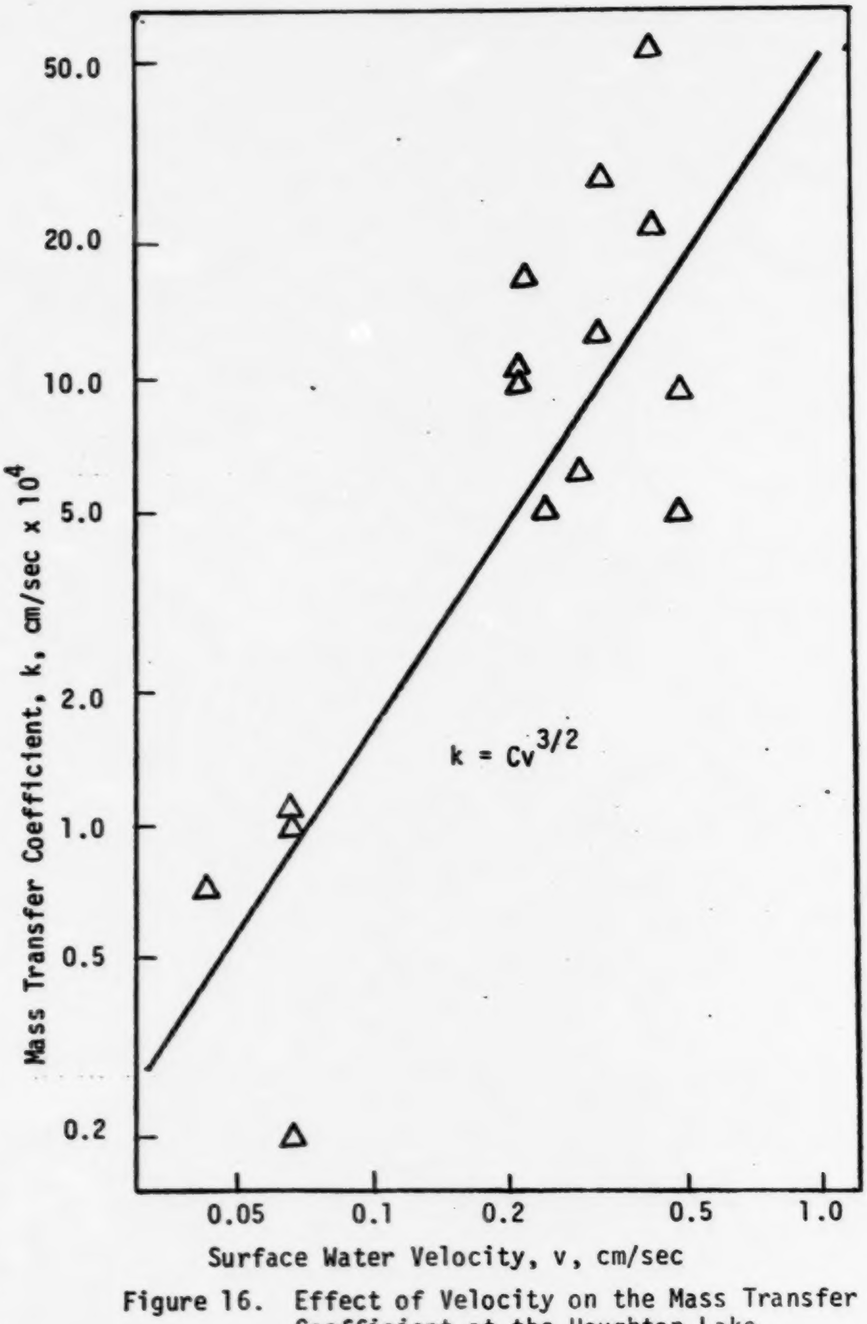


Figure 16. Effect of Velocity on the Mass Transfer Coefficient at the Houghton Lake Treatment Site.

ρ_s is the density of the solid particles, gm/cm^3

ρ_w is the density of water, gm/cm^3

g is the gravitational constant, cm/s^2

D is the thickness of a single layer of particles, or the particle diameter, cm

The critical value of the dimensionless shear stress, S_c, is the point of incipient resuspension. Shields further argued that this critical value could be correlated as a function of the boundary Reynold's number alone, based on dimensional considerations. The boundary Reynold's number is defined as

$$Re_B = \left(\frac{\tau}{\rho_w}\right)^{1/2} \frac{D}{\nu_w} \qquad [5.15]$$

where ν_w is the kinematic viscosity of water, cm^2/s.

Mantz (40) reviews previous experimental studies on incipient resuspension of non-cohesive particles and suggests bounds from cumulative data on an extended Shield diagram. These limits are shown in Figure 17. Mantz (40) also discusses treatment of data for cohesionless flaky sediments, and selection of a characteristic dimension for flakes presents a problem. While data are limited, use of a boundary Reynold's number based on a nominal diameter (defined as that of a sphere having the same volume as the flake), best matches the flake behavior to that of grains on the extended Shields diagram. Critical shear stresses are somewhat lower for flakes at a given Reynold's number.

Other approaches to describing transport and sedimentation of non-cohesive particles have been developed in other disciplines, such as the consideration of solids conveying in industrial processes. Useful concepts and correlations can be found in textbooks which discuss fluidization technology, such as Zenz and Othmer (44).

Potentially useful design tools exist for prediction of solids transport and accumulation in AWT systems. First however, research into the nature and quantities of sediments which are found in wetlands must be completed to provide useful design parameters. Models which work for non-cohesive particles may prove totally inadequate for flocculant organic materials. The presence of litter and plant stems will affect the solids collection and retention, and must be quantified, as well as the effects of channelization. Figure 18 displays the rather sparse data reported on suspended solids removal.

BIOMASS UPTAKE OF WASTEWATER COMPONENTS

Incorporation of nitrogen, phosphorus, and other components into the tissues of plants represents a temporary removal mechanism within the wetland. In a new treatment system, biomass generation is stimulated by the introduc-

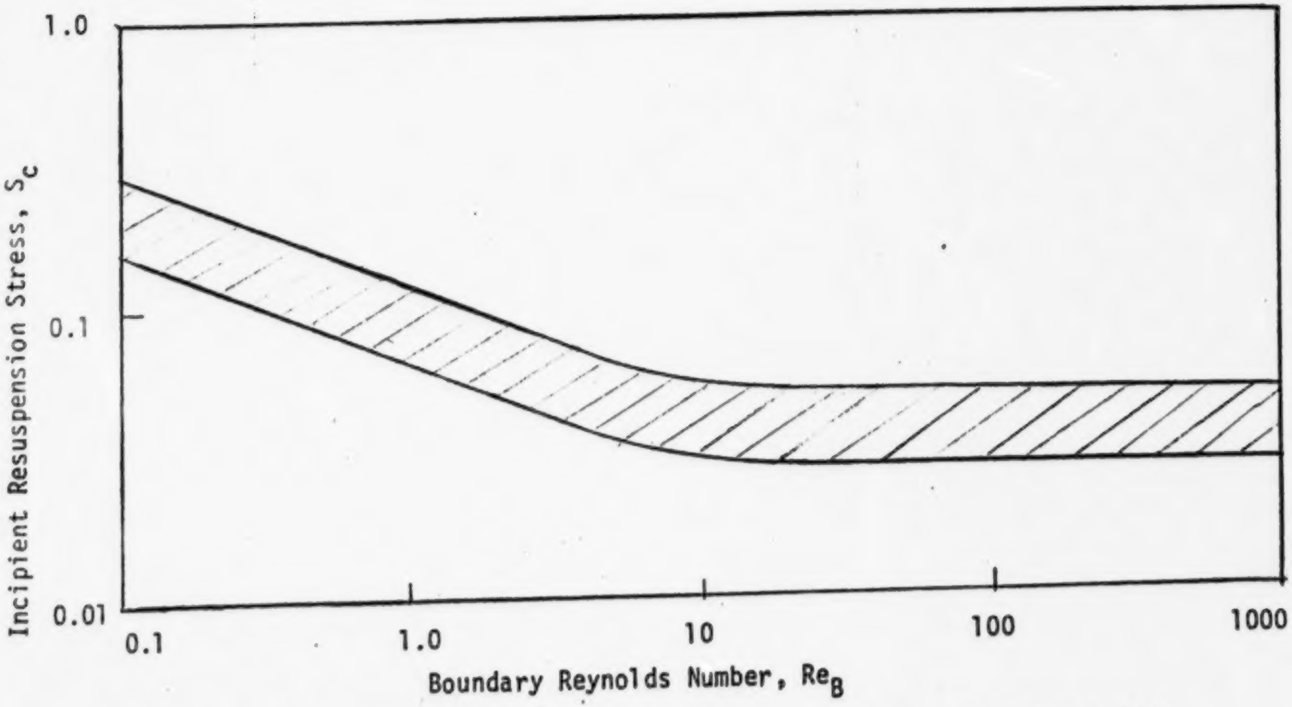


Figure 17. Typical Range of Behavior for Resuspension of Granular Solids. Extended Shields Diagram Adapted from Mantz (1977).

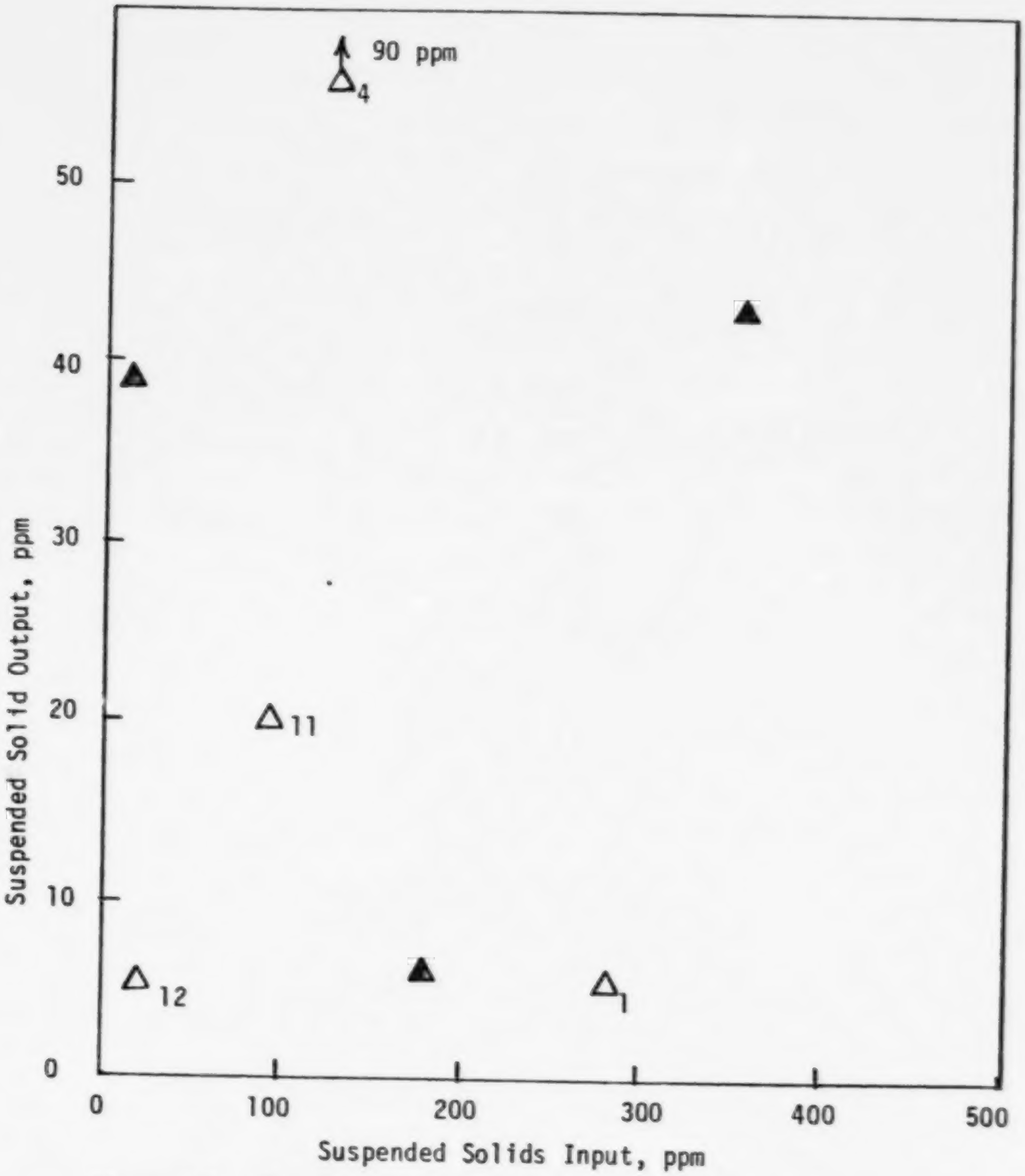


Figure 18. Removal of Suspended Solids by Wetlands.

△ Data for Wetland Treatment Sites (See Table 4 for Identification Numbers)

▲ Data from Stowell, et al. (34)

tion of nutrients, and plant size and areal density increase. Various investigators have reported plant productivity at wetland treatment sites to increase by a factor of two or three (21, 45, 46). Concentration effects have been illustrated by Pratt, et al. (47) in their study of cattail growth. Their results, shown in Figure 19, indicate that the growth rate of individual plants is stimulated by concentrations up to about 7 ppm phosphorus and about 40-50 ppm of nitrogen. In treatment operations, many factors such as climate, water depth, maximum stand density, and even the presence of herbivores, will determine the biomass actually produced per hectare and thus the resulting uptake rates.

Composition data for wetland vegetation, with and without wastewater additions, are summarized on Figure 20. It is apparent that plant growth can generally account for more than five times as much nitrogen as phosphorus. Woody plants and reeds will accommodate greater amounts of nitrogen.

Figures 21 and 22 display current data on nutrient uptake rates by vascular plants in wetland AWT systems. These figures are based upon the biomass production rate during the growing season, and the nitrogen and phosphorus content of the plant tissues. Nutrient concentrations in the surface waters do not show any clear effect on these rates, but in many cases the concentration values used may not be fully representative of the areas used for biomass assay. Nutrients in suspendable solids may not be reflected in these concentrations but may be available for plant growth. It can be seen, however, (with the exclusion of data for first season operations) that phosphorus uptake by vascular plants has been in the range of 0.10 to 0.4 kg P/ha /d. Similarly nitrogen uptake by plants varied between 0.5 and 1.5 kg N/ha/d. This is the approximate magnitude of the nitrogen and phosphorus removal rate which might be attributed to biomass harvest.

Algal growth will also provide a mechanism for component removal from surface waters. The stimulation of algal productivity by wastewater irrigation has been demonstrated by Schwegler (49) as illustrated in Figure 23. In that study, short-term uptake rates of nitrogen and phosphorus of approximately 0.6 kg N/ha/d and 0.1 kg P/ha/d were observed. Light attenuation by suspended sediments and litter limits algal activity to the upper 5-7 cm of the surface water pool. Similarly, as vascular plants develop, shading effects limit periphyton production. Details of nutrient cycling by algae are not well characterized for wetland treatment systems. While periodic algal blooms may provide rapid uptake of nutrients, heavy metals, and other components, the ultimate fate of these substances is difficult to assess. Much is probably released with equal rapidity. Current research has only begun to address the questions about the role of algal detritus in nutrient transport as suspended solids (39).

Data on uptake rates for heavy metals during biomass production in wetland AWT systems are largely unavailable. Most research in this area has been restricted to the assay of plant material in polluted locations, to determine its heavy metals content (55, 56, 57). Typical values are summarized by Stowell, et al. (34) and are shown in Table 7. These values have not been related to the metals concentrations in the surface waters or in the sediments present. Heavy metal tolerance of certain types of wetland biomass

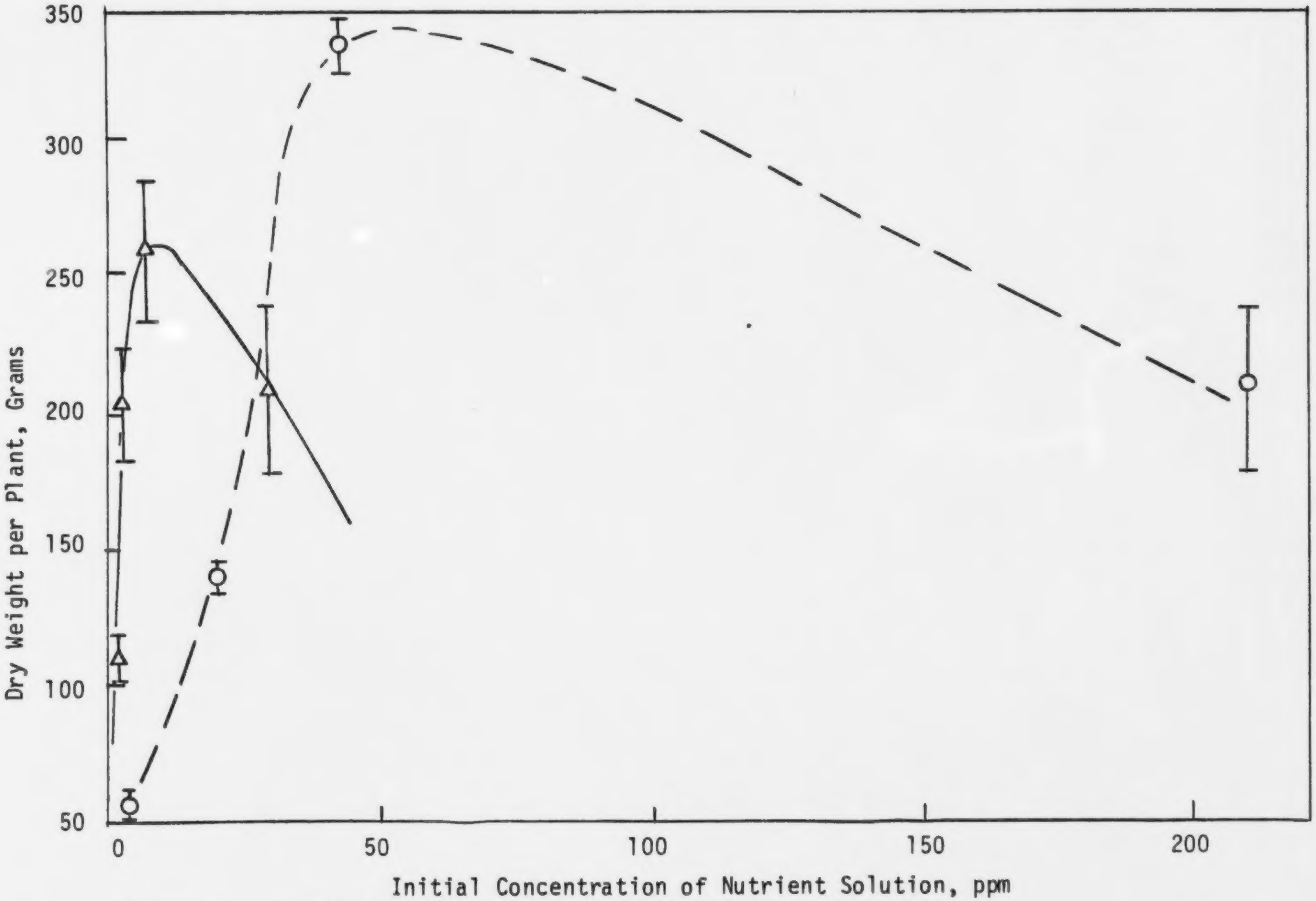


Figure 19. Nutrient Stimulation of Cattail Growth.

○ Nitrogen △ Phosphorus

Adapted from results reported by Pratt et al. (47)

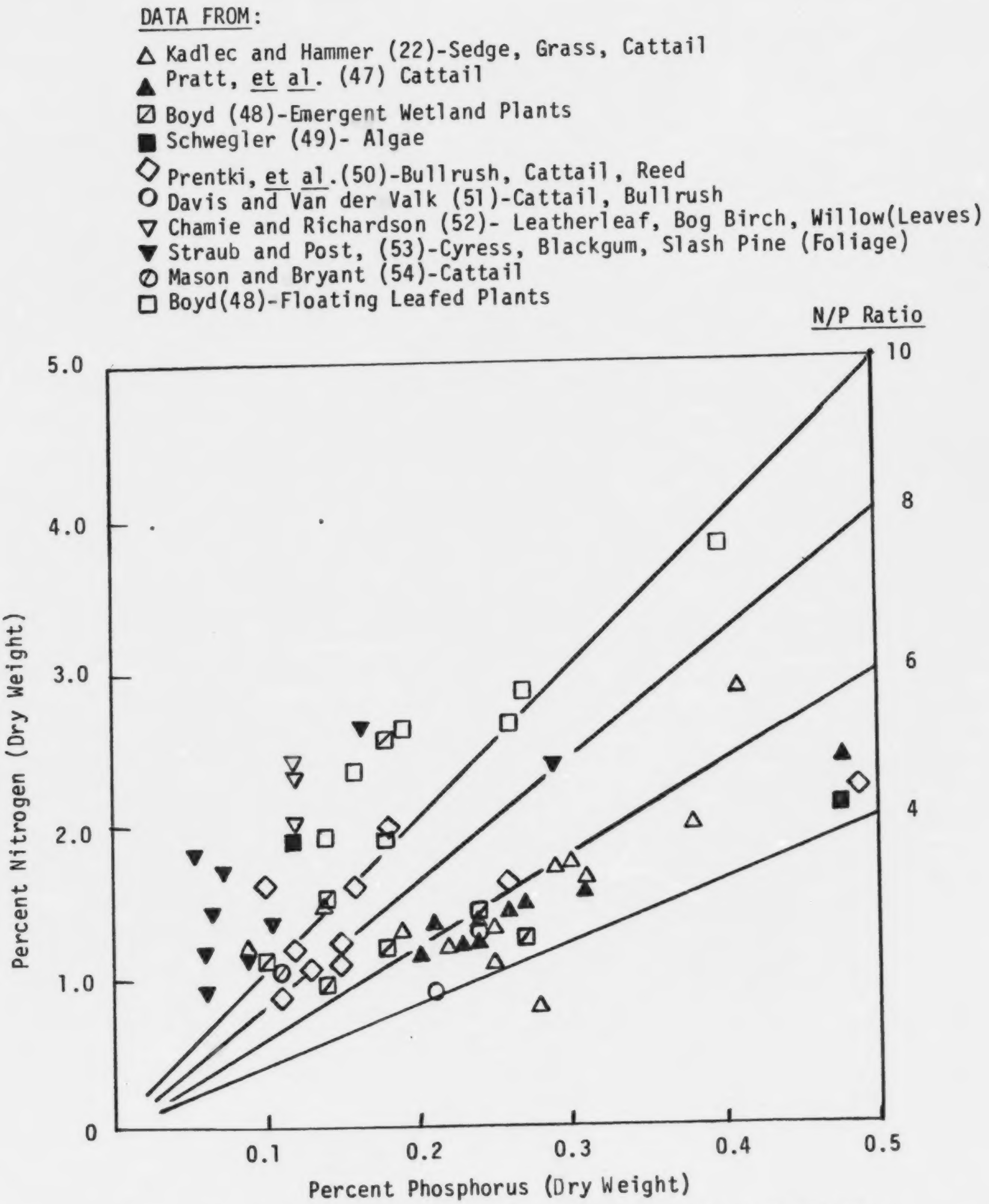


Figure 20. Nitrogen & Phosphorus Content of Wetland Vegetation.

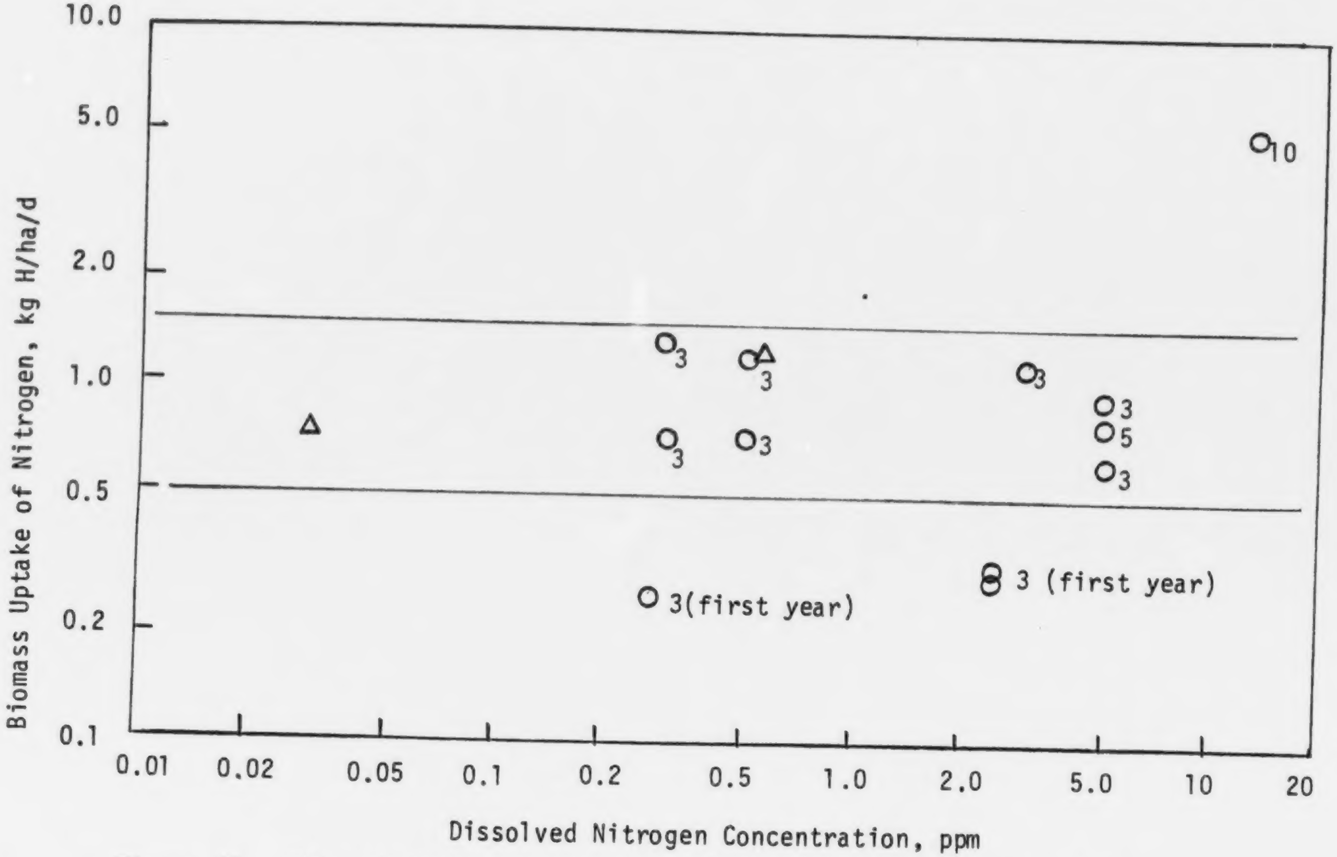


Figure 21. Nitrogen Uptake by Vascular Plants During the Growing Season.

○ Treatment Sites (See Table 4 for Identification Numbers)

Δ Cattail, Natural & Fertilized, Pratt _et al_. (47)

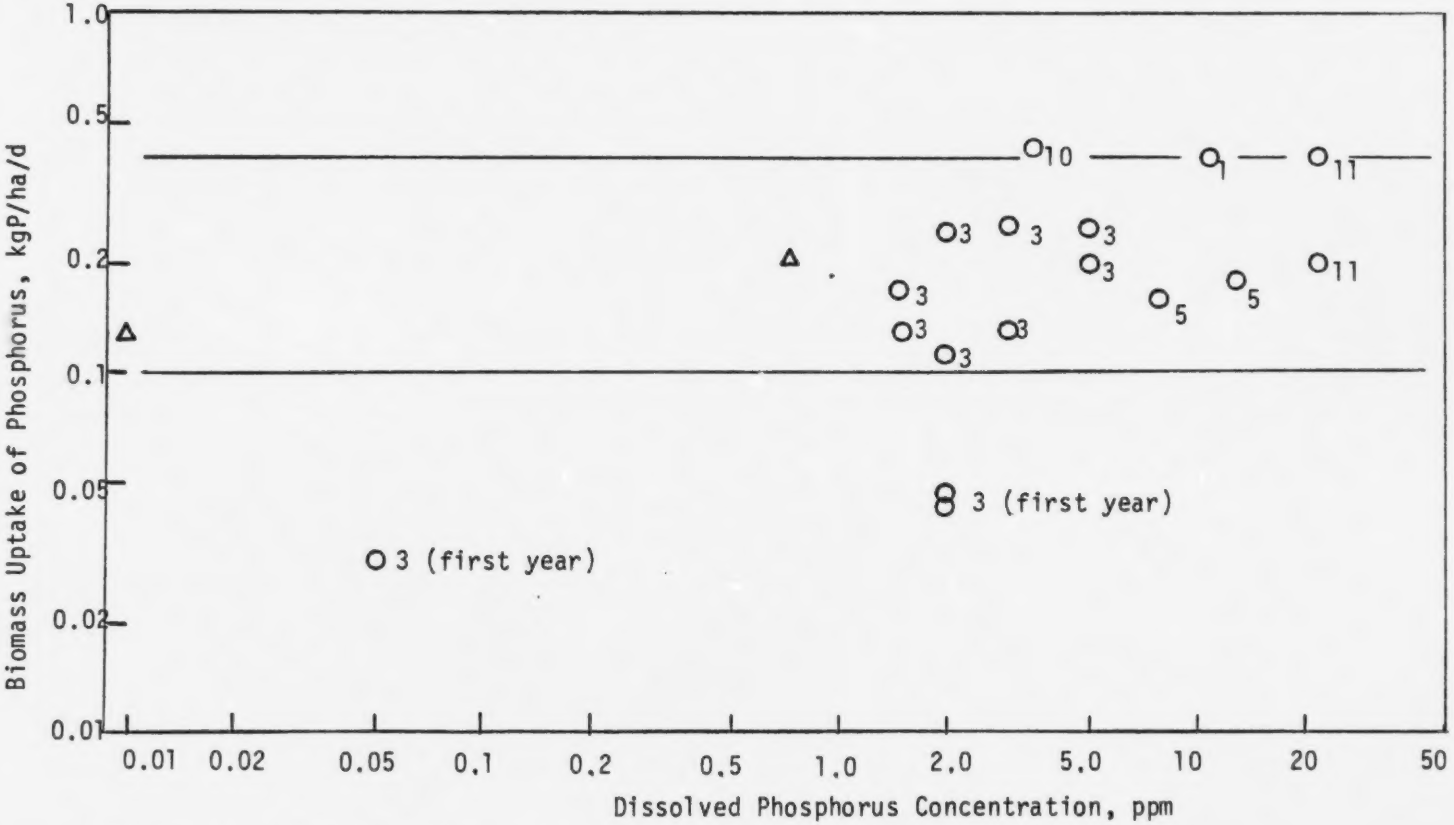


Figure 22. Phosphorus Uptake by Vascular Plants During the Growing Season.

○ Treatment Sites (See Table 4 for identification numbers)

△ Cattails, Natural & Fertilized, Pratt, et al. (47)

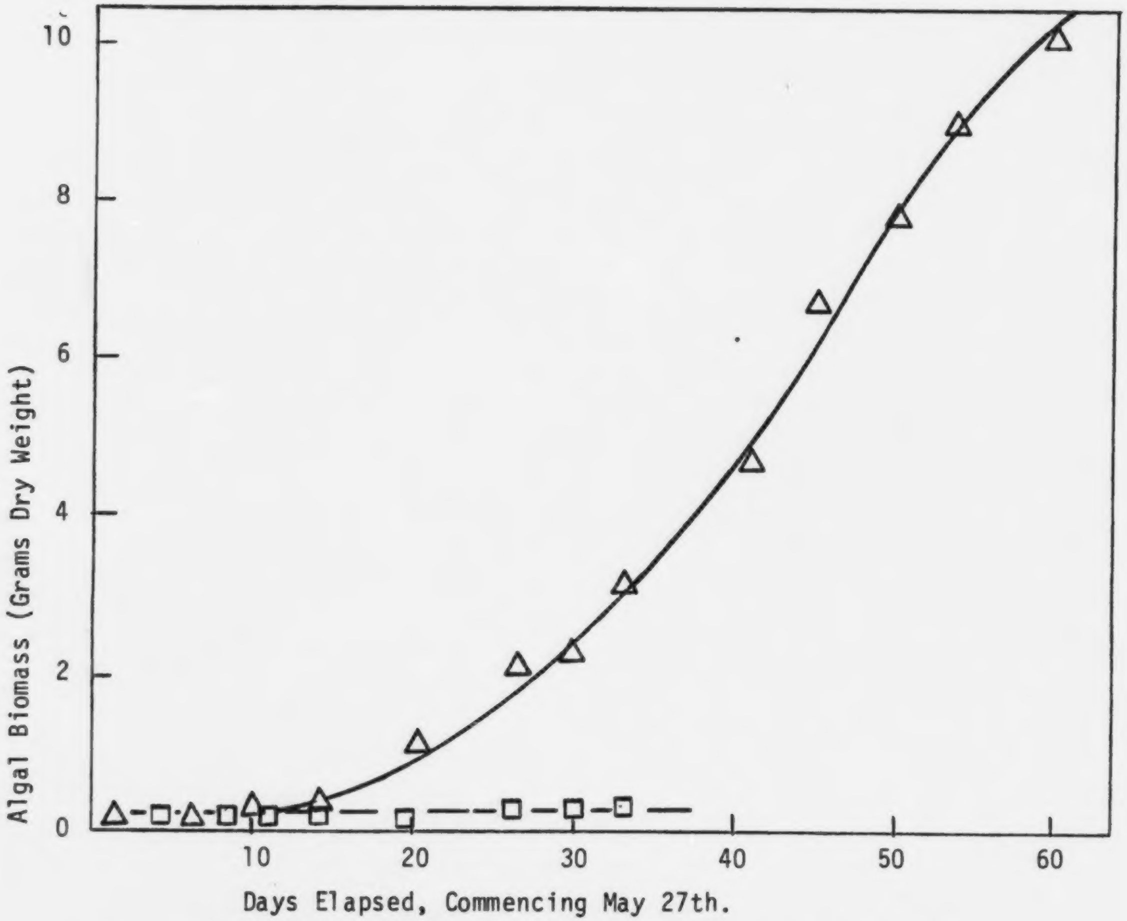


Figure 23. Effects of Wastewater Irrigation on Algal Biomass.
△ Near Wastewater Discharge

□ Control Area
Data From Houghton Lake Treatment Site-Adapted from Schwegler (49)

has also been studied (58, 59). Seidel (60) reports typical values for heavy metal content of Scirpus in clean and in polluted ecosystems as shown in Table 8. Similarly she reports comparative uptakes for various species as in Table 9.

TABLE 7. ELEMENTAL PLANT ANALYSES
ADAPTED FROM STOWELL, ET AL. (34)

Typical values in ppm (dry basis) for plants grown in polluted environments.

Plant	Cd	Pb	Cr	Cu	Ni	Zn
Water hyacinth	10	45	12	48	15	50
Duckweed	17	120	65	79	26	110
Cattail	--	9	8	37	8	30
Bulrush	--	--	12	7	5	50

TABLE 8. UPTAKE OF METALS BY SCIRPUS LACUSTIS MG/KG DRY WEIGHT
ADAPTED FROM SEIDEL (60)

	Cu	Co	Mn	Cr	Ni	V
Healthy lake	18	3	260	2.5	3.5	6
Sewage	50	15	2500	115	30	115

At the low heavy metals concentrations observed in most existing wetland treatment systems, it is very difficult to estimate uptake rates by plants. The upward travel of heavy metals through the food chain by concentration of these low concentrations in the tissue of wetland organisms warrants further research. The higher the concentration of such pollutants in the wastewater, the more important these questions become.

The aforementioned uptake rates represent the influx of nutrients into the biomass compartment during the growing season. If the wetland is not harvested and biomass removed, nutrients will eventually be released by decaying litter, detritus, and standing dead. The rate of release will vary depending on species, climate, and water depth. Litter decay rates have been reported by a number of investigators for various types of wetland vegetation.

TABLE 9. ELEMENTAL PLANT ANALYSES ADAPTED FROM SEIDEL (60) ALL VALUES ARE GM/M^2

Species	P	Fe	Cu	Co	Zn	Ni	Mo	Mn	B
Scirpus lacustris	6.72	2.62	16.13	2.28	168.00	5.75	1.85	4032.00	49.6
Carex stricta	5.98	10.24	15.23	1.96	171.36	6.69	0.79	2638.4	58.21
Iris pseudacorus	6.20	3.22	14.14	2.75	124.0	4.34	0.93	947.36	25.41
Typha angustifolia	3.17	1.58	6.77	0.63	62.92	2.68	0.43	1121.76	35.28
Glyceria aquatica	5.20	2.70	11.65	0.99	151.84	4.14	0.49	1218.88	31.20
Phragmites communis	6.27	4.12	18.82	2.78	165.76	6.85	1.16	743.68	36.74
Acorus calamus	4.64	1.55	6.56	0.85	60.8	1.73	8.48	612.8	91.04
Sparganium erectum	4.99	4.61	7.17	1.37	97.28	2.91	0.31	773.12	51.46
Myosotis palustris	0.64	3.26	3.90	0.46	33.28	1.02	0.17	640.0	9.86
Mentha aquatica	3.70	5.21	14.28	0.91	131.04	3.41	0.79	640.1	64.34

Typical results, obtained by Davis and Van der Valk (51) for Typha glauca, are shown in Figure 24. Submerged litter appears to undergo a rapid weight loss during the first or second month. After this initial period, the rate of decay can usually be described by a first-order rate law,

$$\ln\left(\frac{W}{W_o}\right) = -k_d t \qquad [5.16]$$

where W is the litter weight, kg

W_o is the initial litter weight, kg

t is time, years

k_d is the decay constant, years^{-1}

This rate expression will be valid until the decomposition process is largely complete, leaving a non-decomposing fraction. Table 10 displays decay constants obtained from data in the literature. Decomposition of most standing dead and dry litter is reported to be somewhat faster than that of submerged material (51, 26, 29). Conversely, cypress needles were observed to decay faster at wet sites (62, 29).

In the wetland treatment system, stimulation of additional plant growth creates additional storage for nutrients. Data for vascular biomass increase in the vicinity of the discharge at the Houghton Lake treatment site are shown in Figure 25. Wastewater irrigation was begun in mid-summer of 1978. The biomass figures shown include live vascular plants and litter accumulation, measured at the end of August. As the live and dead biomass pool expands, a sink exists for long-term removal of pollutants from the surface waters. Eventually, however, the biomass per unit area must approach a maximum value, and this growth mechanism for nutrient uptake will cease to function. Materials immobilized by plant growth will be compensated by an equivalent release from the decomposing litter.

Woody plants exhibit a much slower approach to the steady-state condition. The build-up of the woody tissues can be considered for most purposes to be permanent storage compared to the typical time scale for other wetland processes. The annual litter fall of woody plants is only a portion of their total biomass, and the decay rates for woody stems are much smaller than those for foliage (44, 52).

Data on woody wetland vegetation are scarce. The diameter of cypress trees have been shown to increase more rapidly when wastewater is applied (53). Similar results were reported by Nessel and Bayley (29). But when compared on an areal basis with a control area, the Waldo treatment site showed no increase in stem wood productivity. This was due to a much higher stem density at the control site. The relative biomass production and phosphorus storage by cypress and hardwoods were estimated at the Waldo site by Nessel and Bayley, their results are shown in Table 11.

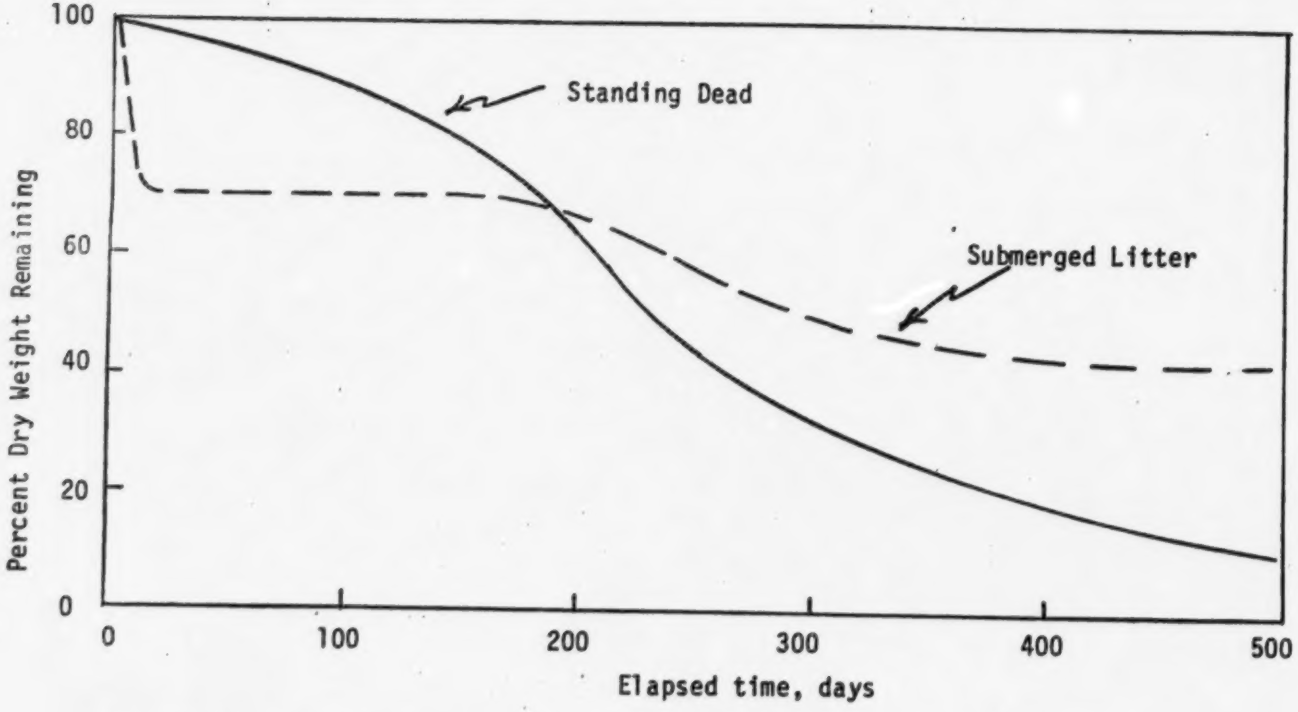
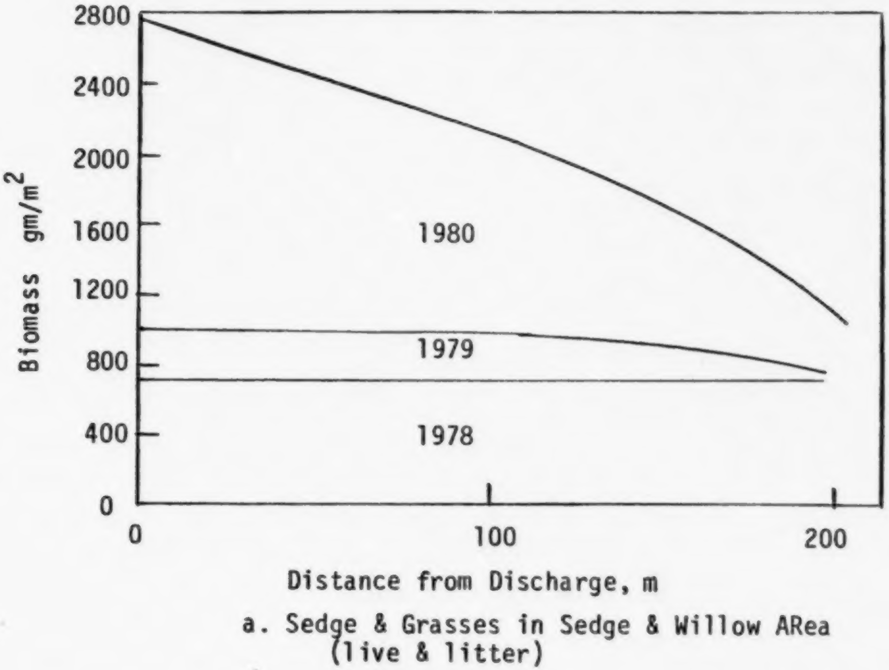


Figure 24. Decomposition of Cattail Litter-Adapted from Davis & Van der Valk (51).

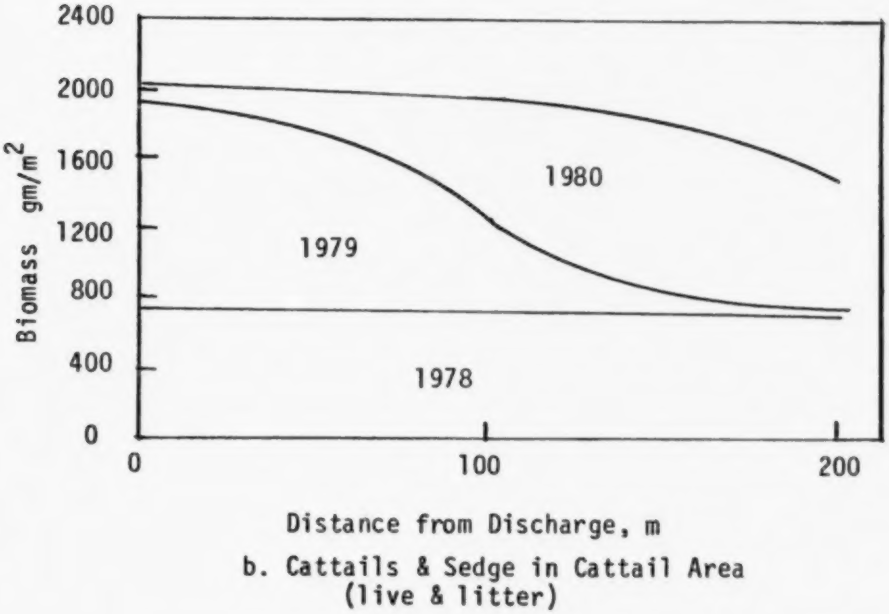
TABLE 10. LITTER DECOMPOSITION RATES

Plant	Decay Constant, years^{-1} from Equation 5.16	Half-life	Source of Data
Leatherleaf (leaves)	0.07	9.9 years	Chaimie and Richardson (52)
Bog birch (leaves)	0.24	2.9	Chaimie and Richardson (52)
Sedge	0.40	1.7	Chaimie and Richardson (52)
Willow (leaves)	0.20	3.5	Chaimie and Richardson (52)
Arrow arum	1.8	0.4	Whigham and Simpson (61)
Wild rice	1.8	0.4	Whigham and Simpson (61)
Bur marigold	1.5	0.5	Whigham and Simpson (61)
Cypress Needles	0.41	1.7	Deghi (62)
Panicium	0.30	2.3	Zoltek, *et al*. (26)
Sagittaria	0.36	1.9	Zoltek, *et al*. (26)
Phragmites	1.40	0.5	Mason and Bryant (54)
Typha glauca (submerged)	0.45	1.5	Davis and Van der Valk (51)
Typha glauca (standing)	1.83	0.4	Davis and Van der Valk (51)

Note: Rate constants, k_d, were determined from litter bag data, the initial rapid weight loss period (30-60 days) was excluded from this analysis.



a. Sedge & Grasses in Sedge & Willow ARea (live & litter)



b. Cattails & Sedge in Cattail Area (live & litter)

Figure 25. Effect of Wastewater Irrigation on Biomass Production at the Houghton Lake Site.

TABLE 11. BIOMASS PRODUCTION AND PHOSPHORUS CYCLING IN TREES AT THE WALDO TREATMENT SITE - FROM NESSEL AND BAYLEY (29)

		Organic Matter		Phosphorus	
		Annual uptake kg/ha	Storage kg/ha	Annual uptake kg P/ha	Storage kg P/ha
cypress	needles	4200	4200	7.3	7.3
	wood	3200	179,200	0.3	14.5
	roots	4100	101,300	2.8	57.6
hardwoods	leaves	2300	2300	3.5	3.5
	wood	3200	105,100	0.4	13.6
	roots	1700	34,100	1.2	23.0

The foregoing discussion has not considered the possibility of succession of one species by another. Insufficient data exist to attempt to quantify such a phenomena. It is plausible, however, that one species could replace another in response to increased water and nutrient levels. This may eventually result in a different value for the maximum biomass per unit area. Thus as succession progresses, additional nutrient uptake or release may occur.

The biomass compartment can be envisioned as shown in Figure 26. Other subcompartments such as standing dead could be incorporated in this model, but little data is available. The release of various components to the surface waters will include many mechanisms, including litter decomposition, rainfall, leaching of standing dead biomass, and the resuspension of particulate material. Once the biomass compartment has ceased to expand, the only natural mechanisms for nutrient removal will be soil building, adsorption on deep soil horizons, and microbial gas production.

In the wetland AWT system, two biomass management techniques are therefore possible. One is to leave the wetland alone, allowing biomass expansion to take up a large portion of the added nutrients. The stimulated growth zone will expand year by year until no space for biomass expansion remains and a new state is achieved. The removal efficiency, particularly for phosphorus, will drop drastically, and a replacement site may be needed. The only mechanism left for nutrient removal via biomass is the fraction of decomposing matter which becomes permanent soil. If the available area is sufficient, a natural steady state could be reached without impairment of

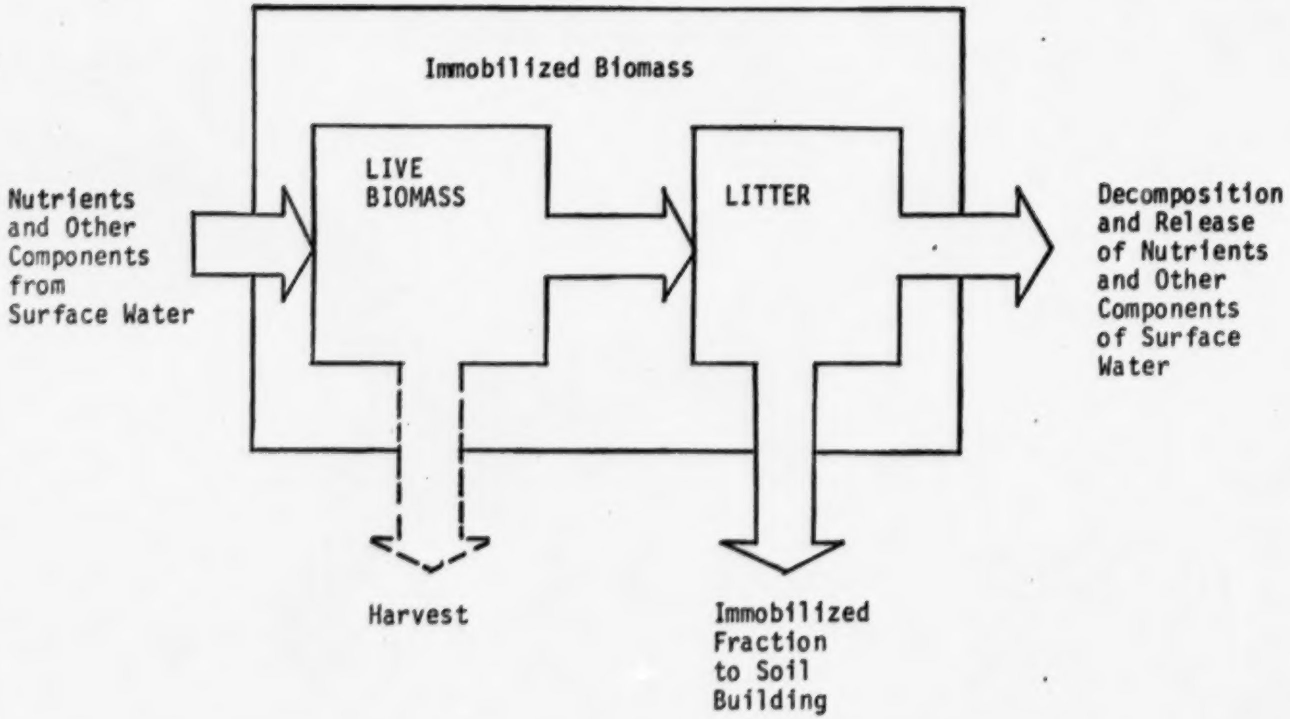

Immobilized Biomass
LIVE BIOMASS
LITTER
Nutrients and Other Components from Surface Water
Decomposition and Release of Nutrients and Other Components of Surface Water
Harvest
Immobilized Fraction to Soil Building

Figure 26. Conceptual Model of the Wetland Biomass Compartment.

efficiency. Net nutrient removal due to biomass activity could equal the amount incorporated into new soil. Soil accumulation will be discussed in a subsequent section, but rates are believed to be relatively low and thus correspondingly large wetland areas would be needed to permit achievement of such a steady state.

Alternatively, some harvesting technique might be employed. Phosphorus, nitrogen and other wastewater components, which would become incorporated into harvestable plants, thus could be removed directly. Lacking the return of these materials to the surface waters through litter fall and decomposition, a long-term steady state could be achieved with less resident biomass. By reducing the accumulating litter pool, the rate of release can be curtailed, and the net annual nutrient removal rate could approach that observed for vascular plants during the growing season (Figure 21 and 22).

REDUCTION OF OXYGEN DEMAND

Wastewater quality is frequently measured by its biochemical oxygen demand, BOD or chemical oxygen demand, COD. These parameters indicate the level of dissolved or suspended substances which are reactive in the presence of oxygen, and therefore could potentially deplete the oxygen present in receiving waters. Wetland AWT systems have been reported to reduce BOD and COD levels, often by 80 to nearly 100% (23). Other investigators report negligible BOD improvements (30). Few data exist for analysis of controlling factors. Measurements are often made on a concentration basis, without adjustments for dilution or concentration by hydrological factors.

In some cases, the natural background level of COD (e.g. 100 mg/l) may be higher than that found in the secondarily treated wastewater to be discharged (63). Stowell, et al. (34) have presented data on the effluent BOD from marsh and peatland systems, and their graph has been reproduced in Figure 27. It appears that effluent BOD levels are quite insensitive to the influent values. This behavior may be the result of sufficient BOD removal in every case to approach background levels.

The reduction of BOD/COD in wetland systems is aided by the large surface area of plant stems and litter, forming a substrate for bacterial populations. BOD/COD which is associated with settling solids are removed from the surface waters and can decay anaerobically. Algae provide high levels of dissolved oxygen further enhancing removal.

While data are insufficient to establish the performance limits for BOD/COD removal in wetland systems, certain information are available. Data on the removal rate as a function of loading rate for BOD at eleven sites are presented in Figure 28. The detailed results for year-round operation, reported by Yonika and Lowry, et al. (27) are shown in Figure 29.

First year batch operations at Humboldt, Saskatchewan were reported by Lakshman (15). BOD_5 removal in the experiments can be adequately represented by a first-order model and showed an average half-life of 2.8 days for the month of September and 4.9 days for the month of October. Starting concentrations ranged from 30 to 100 mg/liter.

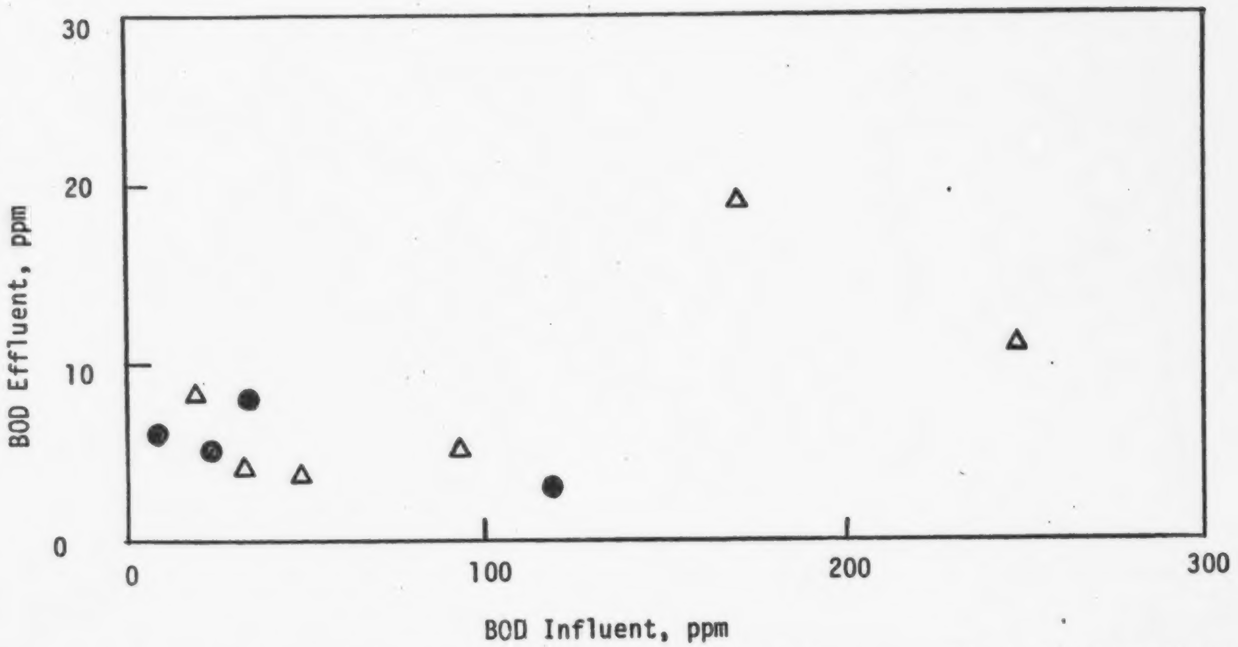


Figure 27. BOD Reduction in Wetland Treatment Systems. Adapted from Stowell, et al., (34).

● Site identified in Table 4.

△ Values Reported by Stowell, et al. (34)

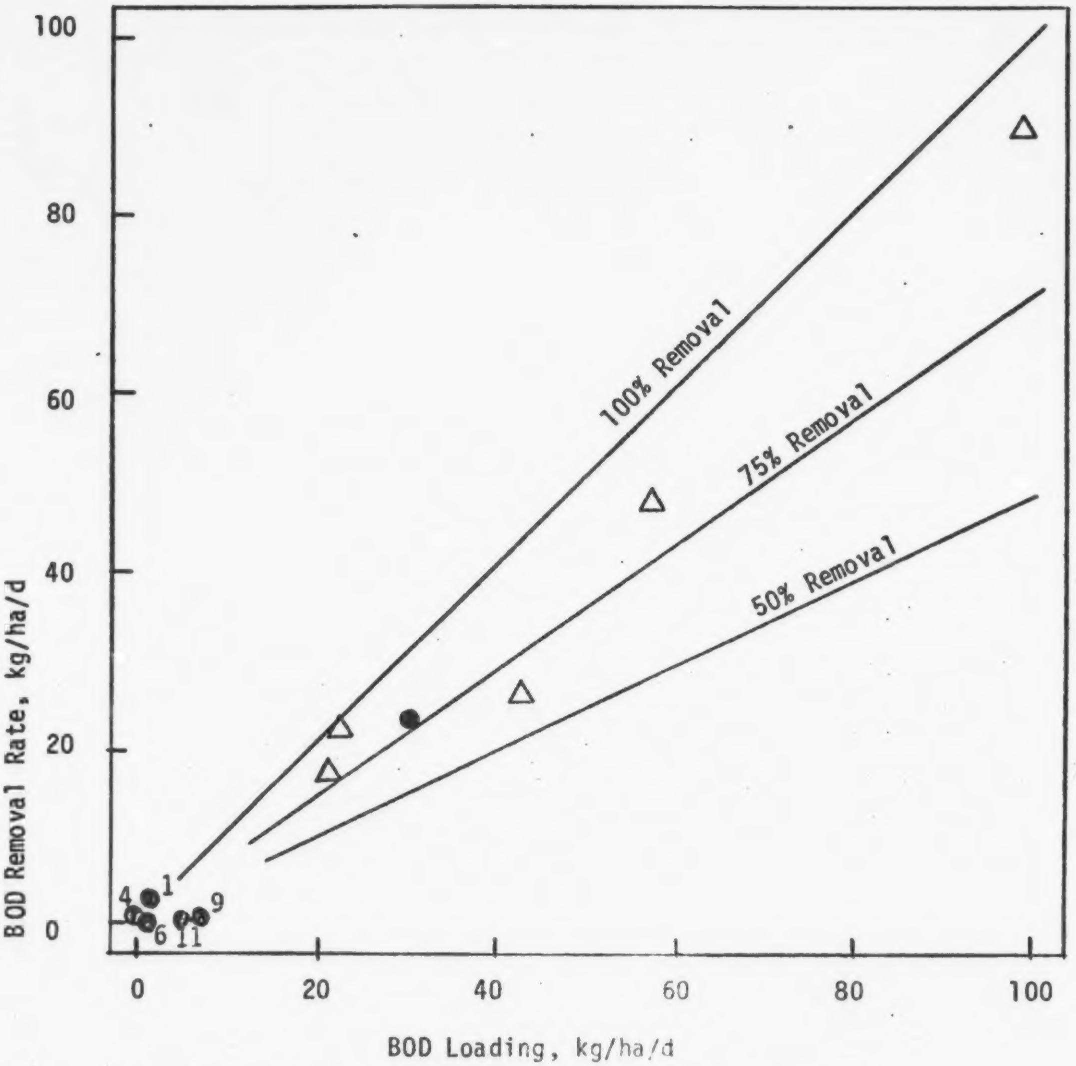


Figure 28. Effect of Loading Rate Upon BOD Removal.

● Sites identified in Table 4

△ Other sites reported by Stowell _et al_. (34)

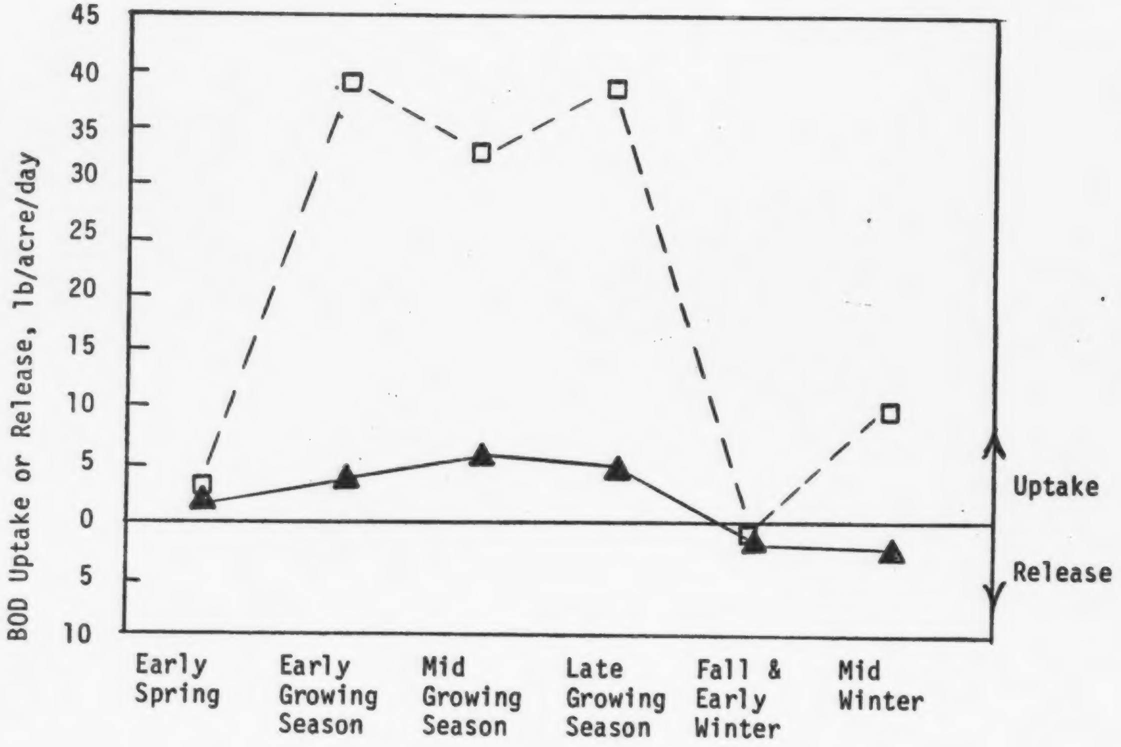


Figure 29. Seasonal BOD Removal Rates at the Great Meadows Treatment Site. Adapted from Yonika & Lowry, et al. (27).

☐ Shrub Marsh near Discharge

▲ Entire Wetland

Odor considerations may be a factor in the allowable BOD/COD loading on a wetland system. Care must be taken to prevent anaerobic conditions from occurring throughout the surface water sheet. Stowell, et al. (34) suggest that BOD loading rates in excess of 60-70 kg/ha/d might result in odor problems. These authors do, however, cite an example in which 100 kg/ha/d BOD causes no objectionable odor in a marsh system.

MICROBIAL PROCESSES

Bacteria play a significant role in the determination of the nitrogen removal rate from wastewater discharged to a wetland. The process known as nitrification can occur in the presence of oxygen:

$$NH_4^+ - N \xrightarrow{\text{Nitrosomonas}} NO_2^= - N$$

$$NO_2^= - N \xrightarrow{\text{Nitrobacter}} NO_3^- - N$$

These reactions are limited by the oxygen supply, and thus are possible only where oxygen can readily diffuse to the reaction site (64). Since the bacterial populations exist primarily on a substrate surface such as litter, plant stems, and soil, only the upper submerged horizons are active for nitrification.

In anaerobic zones denitrification can occur. This process may contribute significantly to the overall nitrogen removal in wetland AWT systems (65).

$$NO_3^- - N \xrightarrow[\text{bacteria}]{\text{anaerobic}} N_2 \text{ and } N_2O$$

Bartlett, et al. (66) studied nitrate removal rates from solutions exposed to soil samples from the Great Meadows wetland. When well-mixed, the initial removal rates from a starting solution of 45.2 mg NO_3-N/liter were reported to be in the range of 13 to 35% per day, with an accompanying generation of nitrogeneous gas. In comparing their results to previous studies these authors observed that slower denitrification rates were measured using reactors where intimate mixing of the soil and solution was not employed. Therefore mass transport limitations are likely to dominate nitrate removal in wetland treatment systems.

Laboratory studies by Zoltek et al. (26) were conducted using peaty marsh soils from the Clermont study site. Removal rates for NH_4^+-N and NO_3^--N were measured, both in the presence of plants and without. Their results are shown in Table 12. In the aerated solutions exposed to the soil surfaces, nitrification proceeded followed by denitrification. This phenomenon can best be seen when the solution pH was maintained near neutral, as for the data presented in Figure 30.

TABLE 12. NITRIFICATION AND DENITRIFICATION ON MARSH SOIL - FROM ZOLTEK, ET AL. (26)

Nitrification study - initial solution containing 40-50 ppm ammoniacal nitrogen, continuously aerated.

Water depth	removal rate, kg N/ha/d with plants	 no plants
15 cm	4.9	2.3
30 cm	5.7	3.6
fluctuating 0-30 cm	7.7	7.8
15 cm (pH controlled 7-8.5)	14.3	15.7

Denitrification study - initial solution containing 40-50 ppm nitrate nitrogen.

Water depth	removal rate, kg N/ha/d with plants	 no plants
15 cm	6.1	6.0
30 cm	7.5	3.6
fluctuating 0-30 cm	5.7	1.7

Since microbial activity is largely restricted to the surfaces of solid substrate materials (e.g. litter and soil), mass transport through the water sheet to reaction zones will likely control the overall rate of these processes. It is important to consider, however, that the accumulation of nitrogen within the biomass compartment may be reduced by bacterial activity. Nitrogen released to the atmosphere by the action of denitrifiers will be permanently removed from the surface waters.

THE SOIL COMPARTMENT

If nutrients, suspended solids, and other substances are to be removed from surface waters, an accumulation within the stationary subsystem must occur. The compartments comprising the stationary portion of the wetland possess various capacities and storage times for wastewater components. The characteristic time for uptake and release of nutrients by plant biomass is short, with the exception of certain woody plants. However, the incorporation of wastewater components into the soil structure by adsorption and by net soil building can represent mechanisms for relatively permanent immobilization.

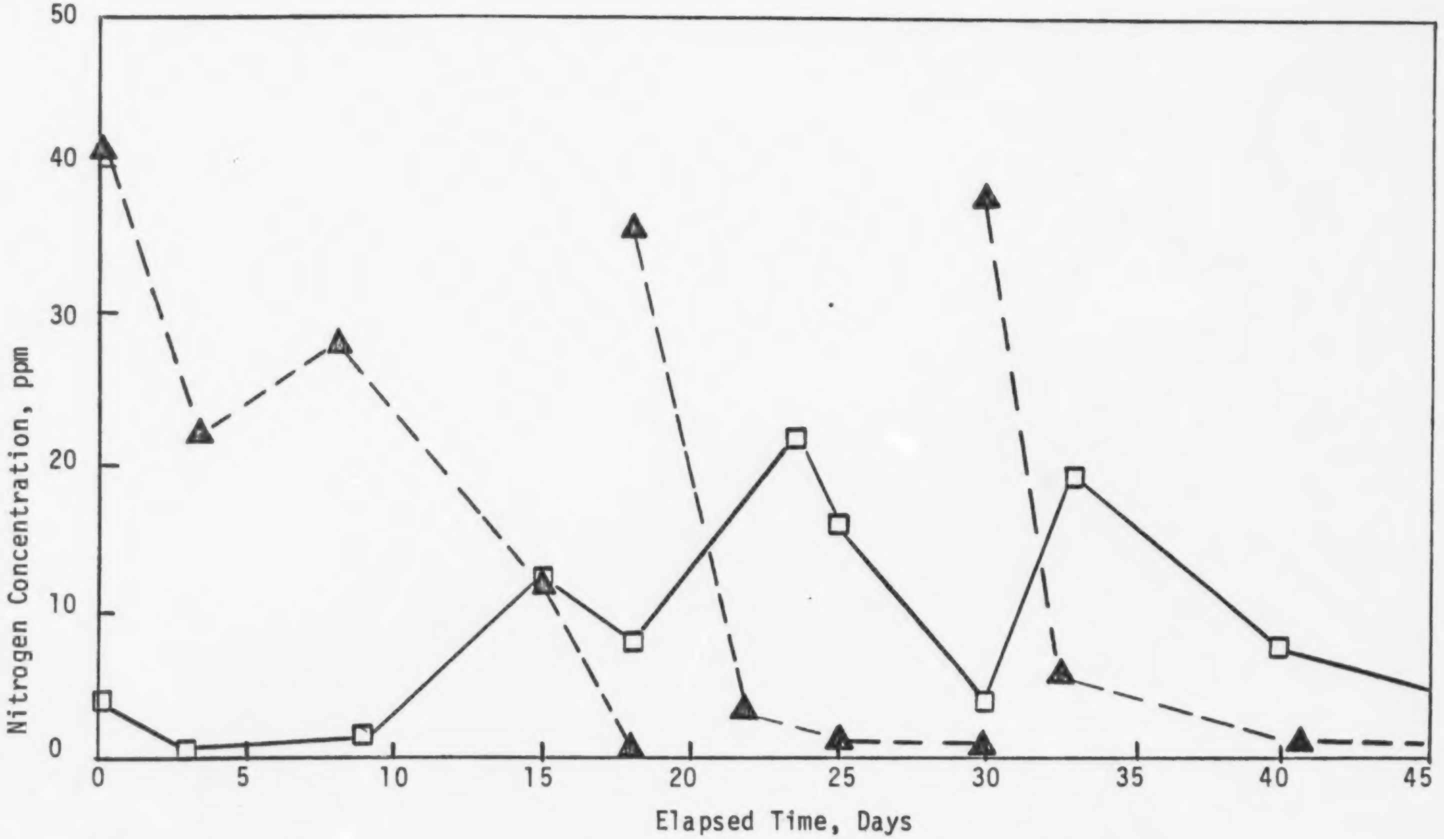


Figure 30. Nitrate & Ammonium Ion Concentrations in Flooded Soil Cores. Nitrification-denitrification data - adapted from Zoltek, et al.(26) Ammonium ion added to soil core on day 0, day 18 & day 30, ph maintained nearly neutral, water depth over core - 15 cm., aeration supplied.

▲ Ammonium-N conc. ☐ Nitrate-N conc.

Adsorption

Phosphorus--

The rapid immobilization of phosphorus from wastewater by organic soils has been reported by many investigators (67, 26, 68, 69). The process has been shown to reach saturation very rapidly as shown in Figure 31, and the uptake is at least partially reversible (67). The phenomena is well-described by a Freundlich-type isotherm for equilibrium adsorption,

$$\log C_s = a_e \log C + b_e \qquad [5.17]$$

where C is the solute concentration at equilibrium in the liquid phase, mg/l

C_s is the solute loading on the soil at equilibrium, mg/gm dry soil

a_e and b_e are constants

Equilibrium data for typical wetland soils are presented in Figure 32. The inorganic phosphorus capacity of a particular soil will be determined by many factors. Adsorption is considered to be limited in part by iron, aluminum, and other inorganic components to provide the means for phosphorus fixation (70, 73, 74, 59). The sorption capacity of organic soils can also be reduced by the presence of inactive inorganic diluents such as sand (75).

Phosphorus profiles in surface water at the Houghton Lake treatment site (presented previously in Figure 11) show the progression of a saturation front, this behavior is consistent with the concept of equilibrium adsorption.

Nitrogen--

The tendency of other wastewater components to adsorb on wetland soils has not been so clearly quantified. Nitrogen compounds undergo a complex set of transformations via biological and chemical reactions. These processes can occur at rates which are rapid enough to hamper experimental attempts to obtain reliable equilibrium adsorption data.

Studies have been undertaken in the laboratory to assess the adsorption capacity of some peat soils for inorganic nitrogen compounds (76). Microbial processes, in particular, make experimental results more difficult to interpret, and sterilization techniques have been shown to modify the soil's adsorption characteristics. Figure 33 shows equilibrium data for the adsorption of ammonium ion. Although data are sparse and do not fit the model proposed in Equation 5.17 as well as phosphate, the behavior may still be approximated by a Freundlich-type model. Uptake of ammonium ion was rapid in these experiments with sorption largely complete in less than one day (for dilute solutions). Alternatively, in the case of nitrate ion, no appreciative sorption on peat was observed. Chloride is likewise not adsorbed by organic soils.

Heavy Metals--

Many investigators have reported that heavy metals are often closely

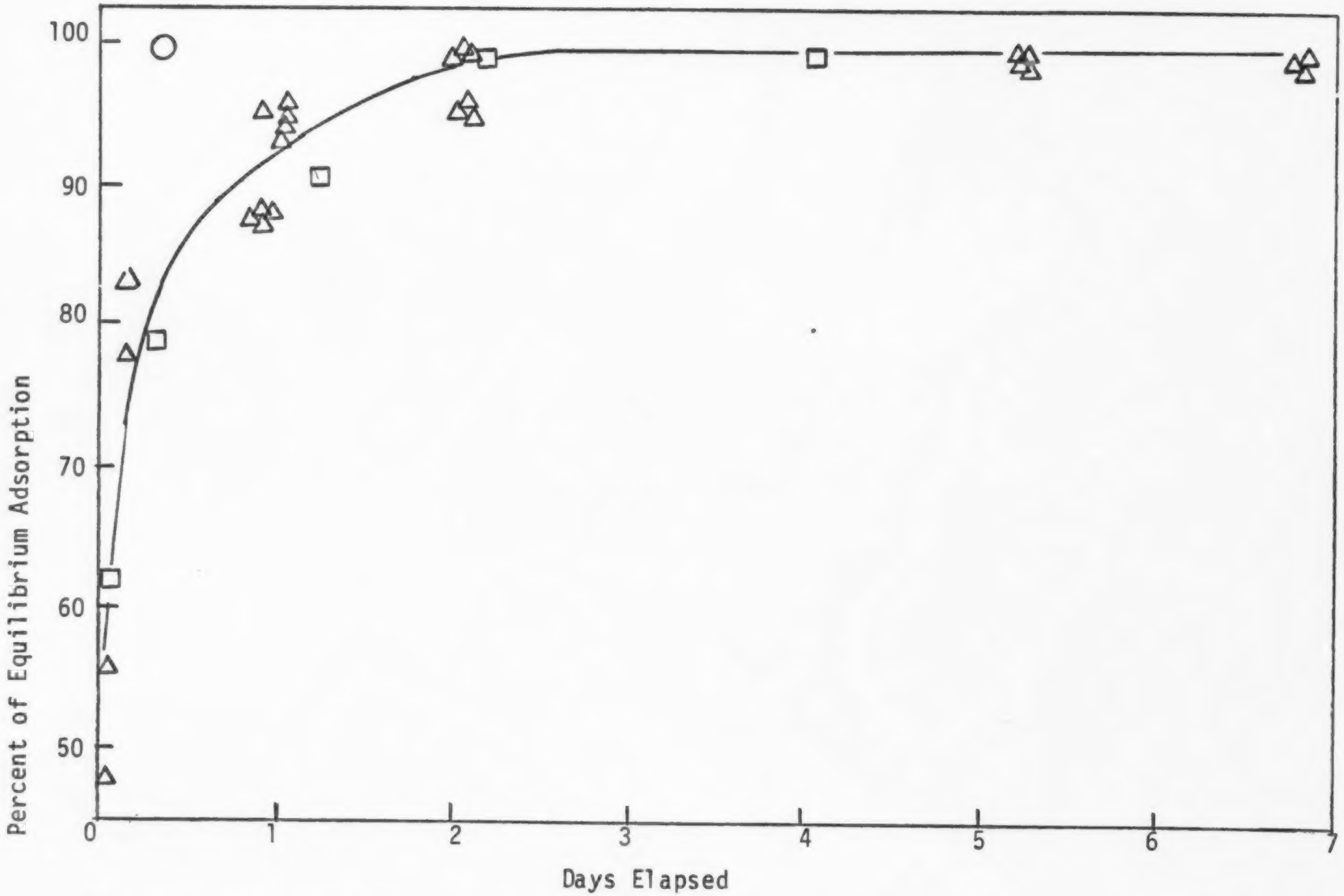


Figure 31. Peat Uptake of Orthophosphate from Aqueous Solution.

△ Sedge Peat, Hammer & Kadlec(67)

□ Houghton Muck, Larsen, et al.(69)

○ Mangrove Swamp Mud, Hesse (68)

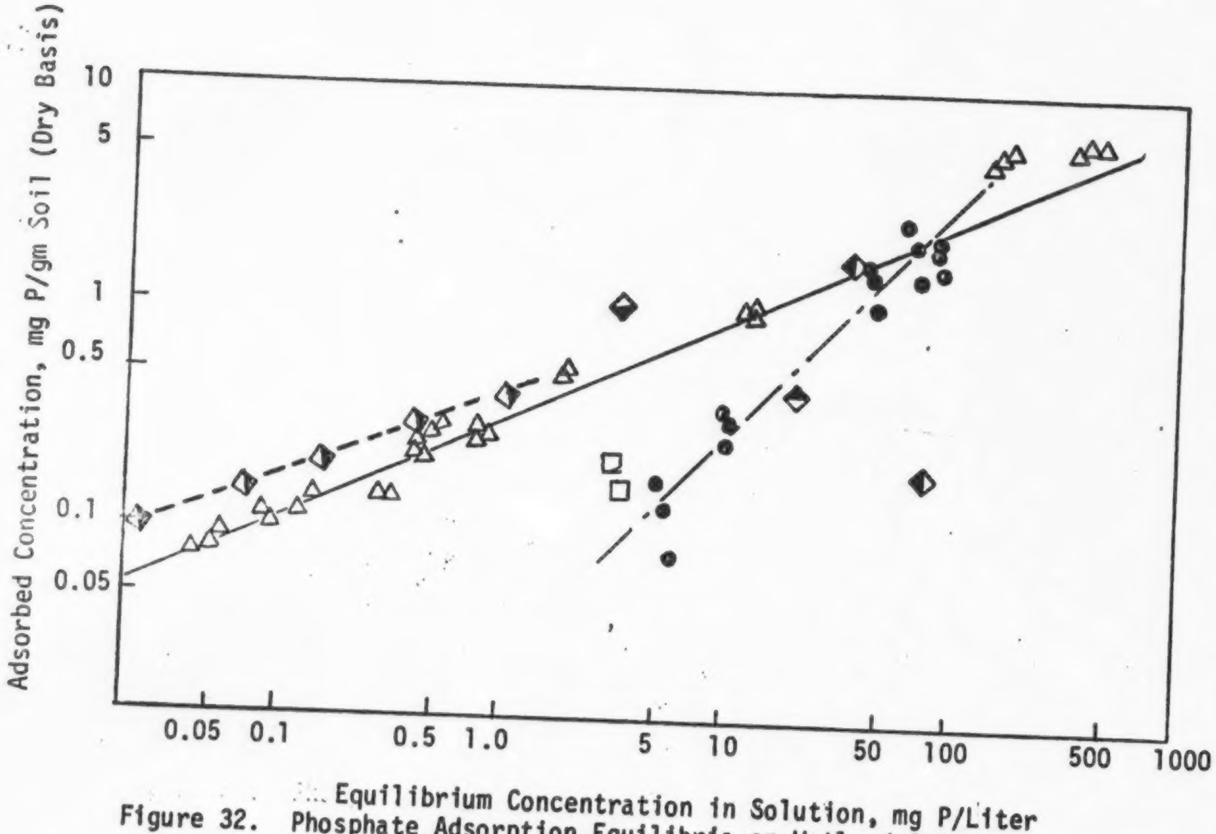


Figure 32. Phosphate Adsorption Equilibria on Wetland Soils.

◆ Doughty (70) ◆ Larsen, et al. (69) ◆ Barrow & Shaw (71)

◆ Rajan & Fox (72) △ Sedge Peat-Hammer & Kadlec (67)

☐ Leatherleaf Peat-Hammer & Kadlec(67) ● Zoltek, et al. (26)

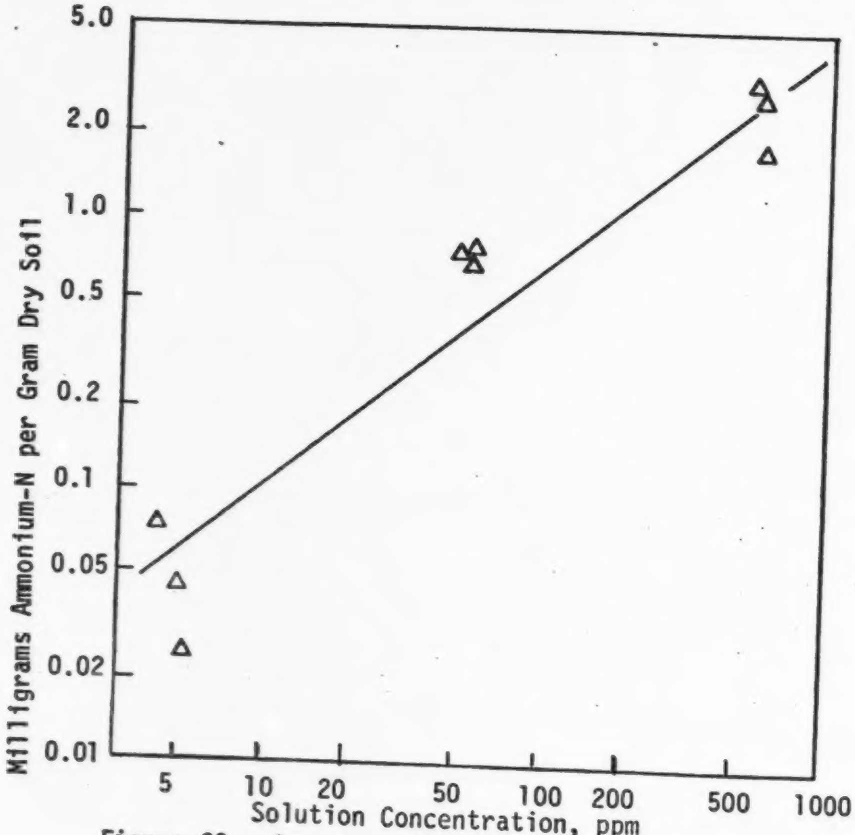


Figure 33. Ammonium Adsorption Equilibrium on Wetland Soil. Sedge Peat from Houghton Lake Treatment Site.

associated with sediments and upper soil horizons (55, 77, 56, 78). Actual measurements of equilibrium uptakes in wetlands used for AWT are difficult to obtain. Literature data consists almost entirely of specific compartmental assays at a single point in time and offer very little information on potential removal rates or sorption equilibria. Metal concentrations in applied wastewater are usually quite low, typically below the detection limits of routine analytical work. A strong affinity for heavy metal sorption would imply that soils could rapidly remove them from overlying waters. Sorption of cupric ion on peat-muck soils has been studied by Sapek (79). A typical uptake curve is shown in Figure 34.

Equilibrium sorption data as available from several sources are shown in Figure 35. These high soil capacities suggest that wetlands can remove heavy metals from wastewater very effectively. Removal rates are likely to be limited only by mass transfer from surface waters to the soil. Soil capacity for heavy metals has been observed to increase with organic content (55, 81), and pH and redox potential have also been shown to play a role (82, 83, 84, 85).

Closure--

In summary, the factors which control the rate and extent of ion sorption on peat and other wetland soils have not been fully elucidated. Rates are fast in comparison to typical biological processes, thus providing a rapid capture mechanism which can make nutrients more readily available to the organisms present. Operating experience with wetland treatment systems has revealed an apparent nutrient saturation phenomena in the vicinity of wastewater introduction, this behavior is consistent with an approach to an adsorption equilibrium. The presence of these fast sorption mechanisms result in the first-order removal rates observed in wetland systems. The rate of nutrient removal in unsaturated zones is limited by mass transfer. Information is lacking on the temperature dependence of adsorption rates, and it is conceivable that during winter operation the sorption step may provide a significant resistance to nutrient removal.

Transport Within the Soil Column

As the upper surface of the wetland soil becomes saturated with an adsorbing solute, this uptake process will be restricted by the ability of the component to penetrate the soil column. Since the upper horizons of wetland soils are often 80-90% water (by weight), dissolved materials can proceed downward from the surface water sheet, diffusing through the soils' interstitial water, and reach new unsaturated surfaces. Bulk flow through the soil due to water infiltration can transport much larger quantities of adsorbing substances to lower horizons. Many wetlands are perched and any applied wastewater will be removed only by overland flow and evapotranspiration. Water infiltration is often restricted by the low hydraulic conductivity of organic soils. Nevertheless, seepage flows must be considered in the characterization of some wetland treatment systems (26, 29, 86).

Vertical transport of an adsorbing substance through the soil column can be modeled as shown in Figure 36. Bulk flows due to water infiltration and the flux due to diffusion can be superimposed, giving

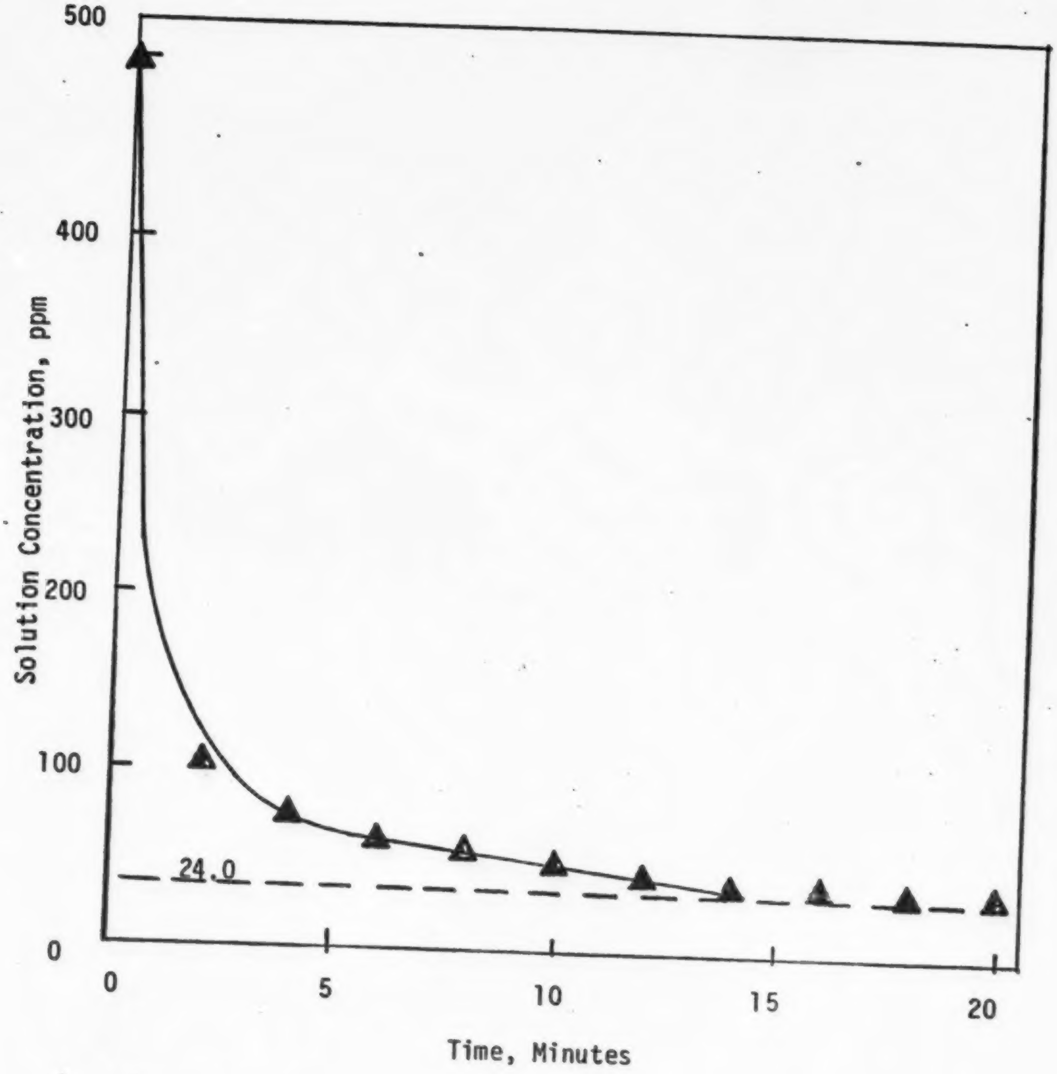


Figure 34. Copper Uptake Rate by a Peat-Muck Soil Adapted from Sapek (79).
System: 2 gm soil, 100 ml Cu_2SO_4 Solution

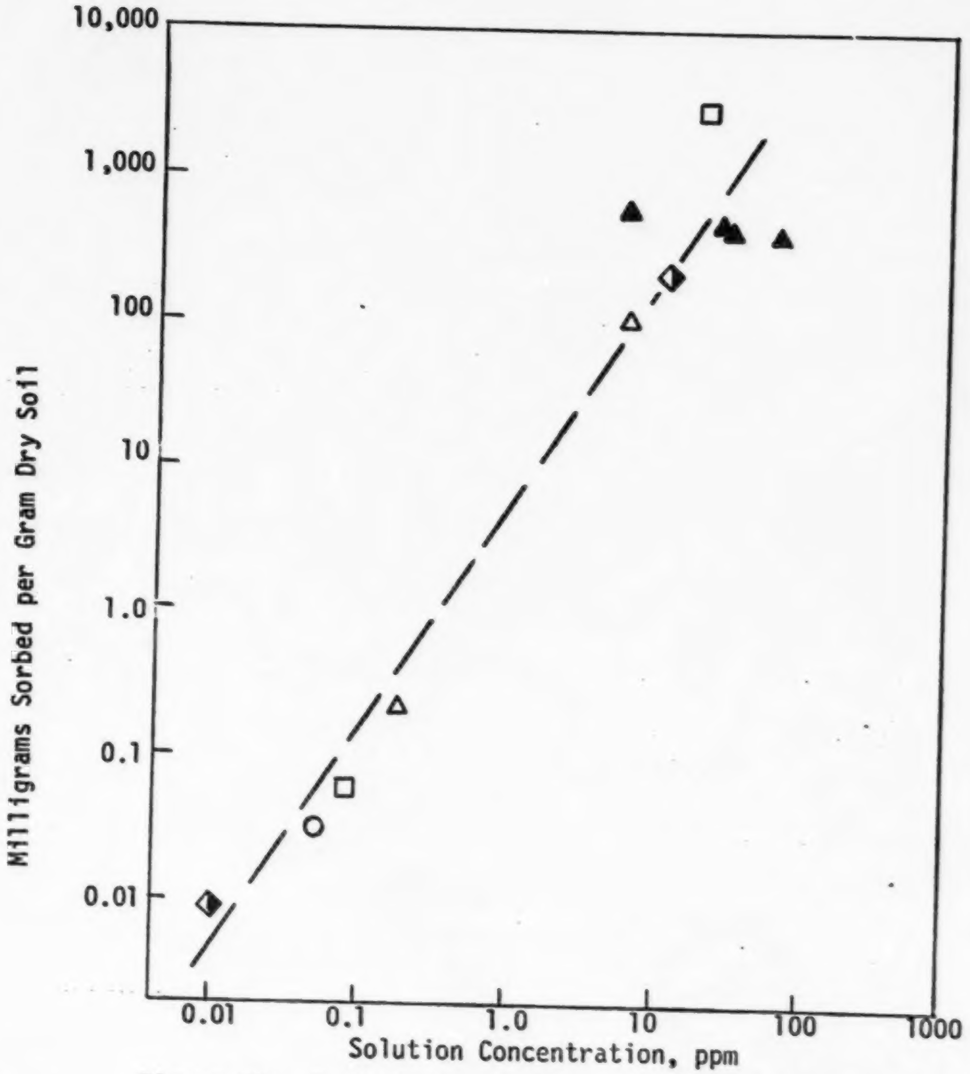


Figure 35. Equilibrium Sorption of Heavy Metals on Wetland Soils.

□ Lead

◆ Cadmium

▲ Copper

△ Zinc

○ Nickel

Data From: Sapek (79)
Adams, *et al*.(80)
Wolf, *et al*.(77)

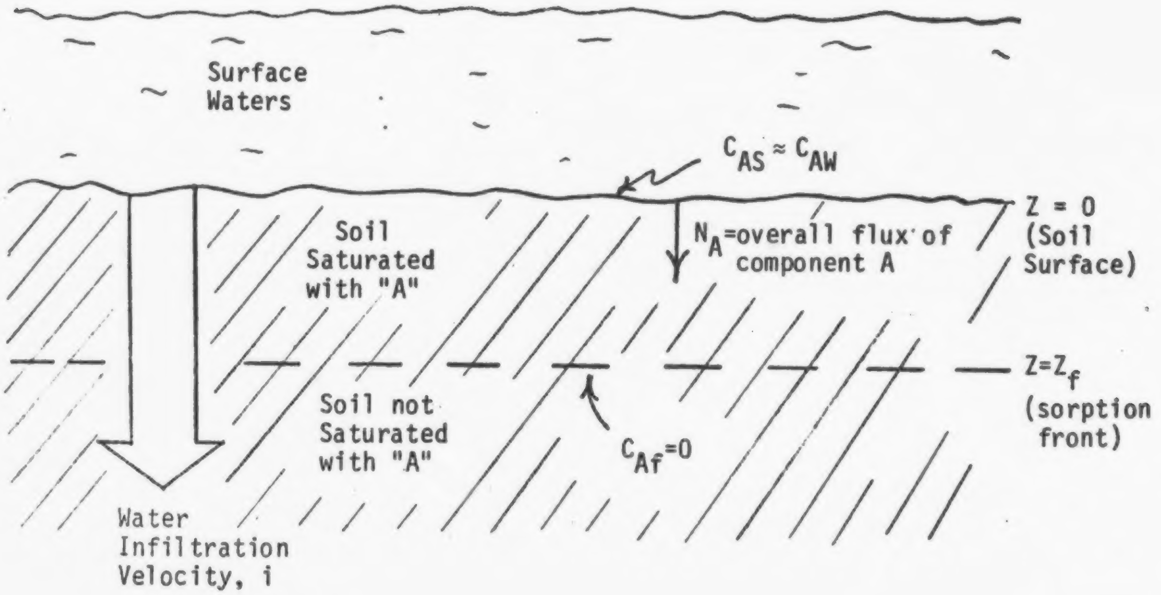

Surface Waters
$C_{AS} \approx C_{AW}$
Z = 0 (Soil Surface)
Soil Saturated with "A"
N_A=overall flux of component A
Z=Z_f (sorption front)
Soil not Saturated with "A"
C_{Af}=0
Water Infiltration Velocity, i

Figure 36. Transport of Adsorbing Substances Through the Soil Column.

$$N_A = -D_A \frac{\partial C_A}{\partial z} + iC_A \qquad [5.18]$$

where N_A is the mass flux of A, gm $A/m^2/yr$

D_A is the diffusion coefficient, m^2/yr

C_A is the concentration of A, gm A/m^2

i is the water velocity downward, m/yr

z is the distance from the soil surface, m

Estimation of the infiltration velocity may be troublesome in wetland systems, requiring careful closure on the water budget. In general, the diffusional term in Equation 5.18 can be neglected in the presence of any significant water infiltration, and the downward flux of all wastewater components can be calculated as the product of the percolation velocity and their surface water concentrations. This means of wastewater renovation is employed in conventional upland seepage beds. As long as the soil column remains unsaturated, efficient removal of many substances can be accomplished before the infiltrating waters reach the ground water supply. Typical removal efficiencies for uplant infiltration systems are shown in Table 13. Operations at the Vermontville wetland treatment site have shown phosphorus to be readily removed by infiltrating water; TKN and particularly NO_3^- -nitrogen were not retained (86).

TABLE 13. WASTEWATER RENOVATION BY INFILTRATION-PERCOLATION -adapted from EPA Technical Bulletin MCD-07, "Evaluation of Land Application Systems," March 1975 (Table 12, pg. 113)

Constituent	Removal Efficiency, %
BOD	85-99
COD	50 +
Suspended Solids	98 +
Total Nitrogen	0-50
Total Phosphorus	60-95
Metals	50-95
Microorganisms	98+

In perched wetlands, transport of adsorbing material down the soil column is by diffusion. Diffusivities for nitrogenous ions have been measured through saturated silt loam by Patrick and Reddy (64), and were found to be 2.5×10^{-6} cm^2/s for ammonium and 1.3×10^{-5} cm^2/s for nitrate. These values are not drastically different than those observed in solutions. The total amount of adsorbed material can be related to the movement of the saturation front using equilibrium sorption data. If the equilibrium relationship may be linearized, the total soil inventory of component A can be expressed as

$$C_{AT} = K_A \overline{C}_{Ai} \qquad [5.19]$$

where C_{AT} is the total adsorbed and interstitial A per unit of wet soil volume, gm A/m^3 wet soil

$\overline{C}_{Ai}$ is the average concentration of A in interstitial solution gm A/m^3

K_A is a constant for component A

Referring to Figure 36, the average concentration in the interstitial solution in the saturated zone can be taken to be one half of a constant surface water concentration. With these simplifications, Equation 5.18 can be solved, for the case where $i = 0$, to predict the progression of the vertical adsorption front:

$$Z_f = \left(\frac{2 D_A t}{K_A}\right)^{1/2} \qquad [5.20]$$

where Z_f is the depth of the saturation zone, m

D_A is the diffusivity of the solute A, m^2/yr

t is the time to reach this depth, years

While the adsorption isotherm for ortho-phosphate is non-linear, the penetration of this ion can be roughly estimated using Equation 5.20. Numerical results for a typical case are presented in Figure 37.

Soil Building

Little data exists on the soil building rate in fresh water wetlands. While sediment accretion rates have been measured for salt marshes, little is known about fresh water areas (87). The accumulation rate of soil in wetland treatment systems due to the combined effects of imported sediments and biomass decomposition has not been measured, but certain observations can allow reasonable speculation. Stewart and Reader (88) cite rates in the range 0.03 cm/yr to 0.06 cm/yr for peat accumulation for northern marshes, determined by carbon dating. This corresponds to a range of approximately 300 to 600 kg per hectare per year (dry weight). The soil accumulation rate at the

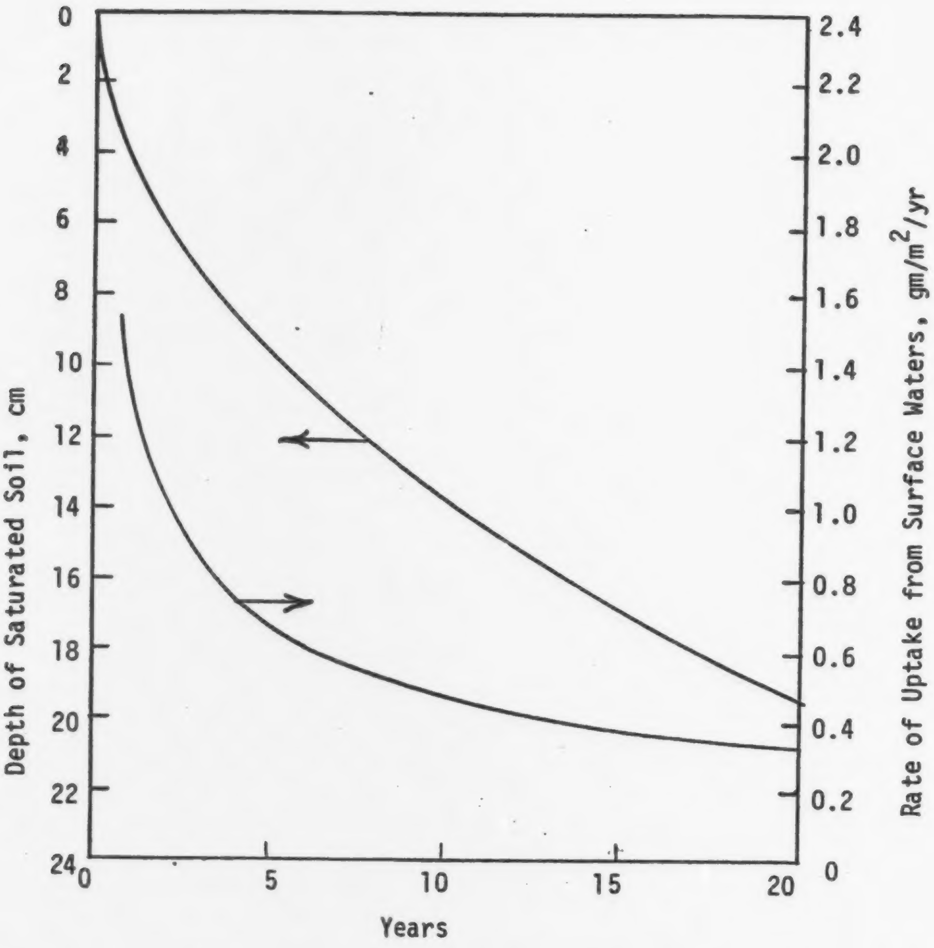


Figure 37. Phosphorous Uptake by Diffusion and Adsorption in the Soil Column. Model Parameters (see equation 5.20):

$D_A = 3.2 \times 10^{-2}$ m^2/yr, C_{AS} = 2.0 gm/m^3, K_A = 32.2

Houghton Lake treatment site, prior to wastewater irrigation was estimated using ^{137}Cs dating. It was found to be approximately 0.2 cm/yr or 2000 kg per hectare per year (22). This is at the upper end of the range 0.1-0.2 cm/yr, quoted by Farnham and Boelter (89) for Minnesota peatlands. A larger data base is needed to allow good predictions of the soil accumulation rate even in a natural marsh, and the effect of wastewater additions must also be assessed. In absence of better information, it may be reasonable to assume that a three-fold increase in the plant biomass production rate will have a similar effect on the soil building rate.

The actual composition of the accumulating soil in wetland AWT systems will determine the rates at which phosphorus and nitrogen can be accumulated. Typical compositions of organic soils are shown in Table 14. After three years wastewater treatment at the Houghton Lake site, no appreciable difference was observed in composition of the top 5 cm of soil near the discharge (22).

TABLE 14. NITROGEN AND PHOSPHORUS CONTENT OF TYPICAL ORGANIC SOILS

Type of Soil	% Nitrogen	% Phosphorus	Source
Fen Peat	2.5	0.25	Ogg & Robertson (90)
Peat	3.5	0.7	Denisov (91)
Grass land marsh	2.4	0.15-0.45	Valenski (92)
Sedge Peat	3.5	-	Maciak & Söchtig (93)
Sedge-moss peatland	3.5-3.7	-	Maciak & Söchtig (93)
Muck from reed peat	4.2	-	Maciak & Söchtig (93)
Reed peat	3.9	-	Maciak & Söchtig (93)
Alder peat	3.4	-	Maciak & Söchtig (93)
Muck from wood peat	3.6	-	Maciak & Söchtig (93)
Sedge-willow peatland	2.1-2.9	0.07-0.13	Kadlec, et al. (76)
Sedge peat	1.7-2.8	0.05-0.15	Kadlec & Hammer (22)

Other factors may also prove important. The suspended solids load in the applied wastewater must be considered. Research on the transport of such material in wetland systems has just begun. Erosion or dissolution mechanisms may further affect the soil building process. The organic substrates, histosols, found in most wetlands are comprised in part by polymeric compounds with acid functionality, specifically humic and fulvic acids. Natural surface waters in peatlands typically have a pH in the range of 3 to 6.5, and the soil/water system exhibits a large buffering capacity to alkaline additions. Wastewater often is alkaline ($7.5 < pH < 9.0$). It can be speculated that humic and fulvic acids, in fulfilling their buffering function, could be drawn into solution, thereby literally dissolving the existing soil. The apparent removal of peat deposits at the Kinross treatment site (94) is consistent with such speculation.

MODEL SUMMARY

It appears that removal of dissolved nutrients from surface waters is controlled by a two-step process. The process consists of delivery and consumption. Consumption occurs principally at the surfaces of the soil, litter, plant stems, and algal mat. Delivery is accomplished by convective mass transfer within surface waters or by downward flow due to water infiltration. In the absence of downward flow, mass transfer limits the rate of nutrient removal. Consumption consists collectively of a number of processes (see Table 4) which initially are relatively fast, but some will slow considerably as wastewater treatment continues. Adsorption will reach an equilibrium in the upper soil horizons reducing the average areal uptake rate. Similarly, biomass expansion, which offers a sink for nutrients, will also reach a saturation condition, where the release of nutrients due to litter decay offset any uptake in new growth. Woody biomass production allows longer immobilization of nutrients and constitutes a relatively permanent removal mechanism. Soil production also represents a long-term removal process but is quite slow. While data are extremely sparse, the same basic behavior as for nutrients can be anticipated for heavy metals.

Two treatment regimes will exist in an older wetland system. In the vicinity of the wastewater discharge a "saturated" region will exist. Here component removal rates will be quite slow, comprised of the uptake rates due to (1) adsorption deep in the soil column, (2) incorporation of material into new soil and woody plants, and (3) microbial release of gases to the atmosphere. Outside this "saturated" region, surface water concentrations of wastewater components will drop exponentially with distance. In this latter zone of rapid removal, it is the transport of dissolved components through the surface waters which limits the overall rate. The amount of wetland area needed for this zone of fast removal will be determined by mass transfer considerations and for constant operating conditions (depth, velocity, etc.) will not change. The zone in the "saturated" regime will continue removal at a rate which is slow but insensitive to modest changes in water flow or depth. The expansion of this saturated region will continue until the area is sufficient to allow all incoming wastewater components to be removed by water infiltration, incorporation into new soil and woody biomass, or release to the atmosphere. If the wetland area is less than that required for total retention of pollutants, breakthrough will occur. In this case, only a portion of the wastewater components fed to the wetland will be retained and collection efficiency will drop sharply.

Harvesting plant biomass is a direct method of preventing saturation of the biomass compartment. Nitrogen, phosphorus and other wastewater components can be removed from the wetland system. Higher removal rates can be maintained indefinitely with limited area using this technique.

To employ this conceptual model in the evaluation of wetland system designs, it must be cast in mathematical terms. The resulting equations and examples of design calculations are presented in Section 7.

SECTION 6

WETLAND SYSTEM DESIGN: SYNTHESIS

The design process consists of two distinct phases, synthesis and analysis. Synthesis is the development of a plan for a wastewater treatment facility. Analysis is the evaluation of that plan, and concludes by acceptance of the proposed design, or rejection and another try at synthesis. There are no explicit equations for synthesis. Design parameters are chosen based upon past experience or educated guesses.

A wetland treatment system can be established at a natural marsh, or an artificial wetland can be assembled. The artificial wetland allows the designer more latitude in his choice of physical features. In either case, operating parameters must be established as part of the design.

NATURAL WETLANDS - SITE SELECTION

If a wetland treatment system is to be built in a natural wetland, the designer may have little freedom in synthesis. This phase may consist largely of site selection. Since one of the principal costs in wetland treatment is a wastewater delivery system (piping, pumps, etc.), proximity of the site is fundamental. Sutherland (95) has presented estimates of the break-even distance for wetland facilities.

Technical questions are not the only ones which the designer must address. Land ownership, political considerations, and public attitudes must be investigated. In the case of a natural wetland site, environmental impacts will be of particular concern. It is extremely important to maintain open channels of communication between the designers and the community, regulatory agencies , and any other concerned parties.

Site identification and preliminary evaluation can be accomplished by collection of basic information which is readily available. The location, size and type of potential treatment sites should be determined. Inspection of U.S.G.S. maps and aerial photos are helpful. Ground level visual inspection of a site often reveals important discrepancies between reality and previous descriptions of the wetland. The type and depth of soil should be evaluated. Collection of existing data on hydrology and water quality, both for the wetland and the treatment plant allow estimation of the site's qualitative potential. All links in the network of ownership and management of the site should be determined. Finally, the water quality requirements for the final effluent should be ascertained. With this information, the feasibility of using the wetland treatment alternative can be assessed.

If promising, a preliminary design and cost estimate would be prepared. Site specific information will be required. Typical data to be obtained are listed in Table 15.

TABLE 15. COLLECTION OF SITE SPECIFIC DATA FOR EVALUATION OF A PROPOSED TREATMENT SITE

Water Budget

- Annual precipitation, cloud cover and radiation data acquisition.
- Streamflow data.
- Water level records for wetland and adjacent water bodies.
- Subsurface flow patterns.
- Surface elevation survey.
- Overland flow patterns.

Seasonal Water Quality

- Nitrogen, phosphorus, chloride.
- Coliforms, BOD, suspended solids, TDS, etc.
- pH, temperature, conductivity.

Soil Processes

- Type and depth of peat, detritus.
- Ion exchange capacity of peat.
- Permeability (hydraulic conductivity).

Flora and Fauna

- Algae inventory.
- Plants - cover map, identify endangered species, nutrient status.
- Invertebrate inventory.

Use Patterns

- Vertebrates (muskrats, beaver, ducks, geese, etc.).
- Human

PHYSICAL FACILITIES

With a natural wetland, the only construction needed is often a wastewater delivery line. Since wetlands tend to be at low elevations, delivery can sometimes be accomplished without a transfer pump
Typical system configurations are shown in Figure 38. If for any reason it is desired to chlorinate the wastewater before discharge, provision must be provided to allow dechlorination before the water enters the wetland. Damage to the ecosystem might otherwise occur. Dechlorination can be accomplished by retention of the chlorinated water in a pond prior to release.

Wastewater can be effectively applied to the wetland by a number of schemes. If flows are small (less than about 100,000 gallons per day) water can be discharged from several nozzles or even at a single point. Larger flows can be better accommodated by a linear discharge. This can be conveniently obtained by using gated irrigation pipe. The choice of material for distribution lines is generally aluminum irrigation pipe or plastic (PVC) pipe. At northern sites, provision for draining the lines in winter should be included, to prevent damage by ice. In some cases, these lines can be run directly on the surface of the wetland soil, however, provision should be made to prevent the pipe from sinking into the peat under its weight when filled. The distribution piping has been successfully supported by logs (96) or elevated on a platform which also serves as a convenient walkway (76). Trenches could also be used to distribute wastewater across the width of a wetland. Care must be taken however to assure that such a trench is perpendicular to the direction of wetland gradient. If water can flow downgradient in a trench or other channel, severe by-passing of effective wetland surface will occur. Accurate determination of the direction of maximum gradient can prove very difficult.

Placement of pipe, platforms and other material in the wetland can pose a problem. In northern climes, this is often best accomplished when ice cover has formed. Heavy equipment can then be used with minimal residual damage to the vegetation.

ARTIFICIAL WETLANDS

The construction of artificial marshes for wastewater treatment theoretically provides a number of technical advantages. Control can easily be maintained over water levels and flow rates. The soil, plants, and other component parts included in the system can be selected for their ability to treat wastewater. Treatment cells can be shaped like ditches or like large basins. They can be lined to assure bottom seal. The wetland can be built in a configuration which permits easy harvesting of biomass. Cells can be operated in batch-mode, offering a reliable control on the quality of effluent. The artificial wetland can be located conveniently.

Even these technical advantages may be overshadowed by the political advantages. While objections are sometimes raised to wetland treatment sites utilizing natural marshes, the artificial wetland concept circumvents much of the controversy. In many aspects the constructed wetland is akin to a piece of processing equipment at the municipal treatment plant.

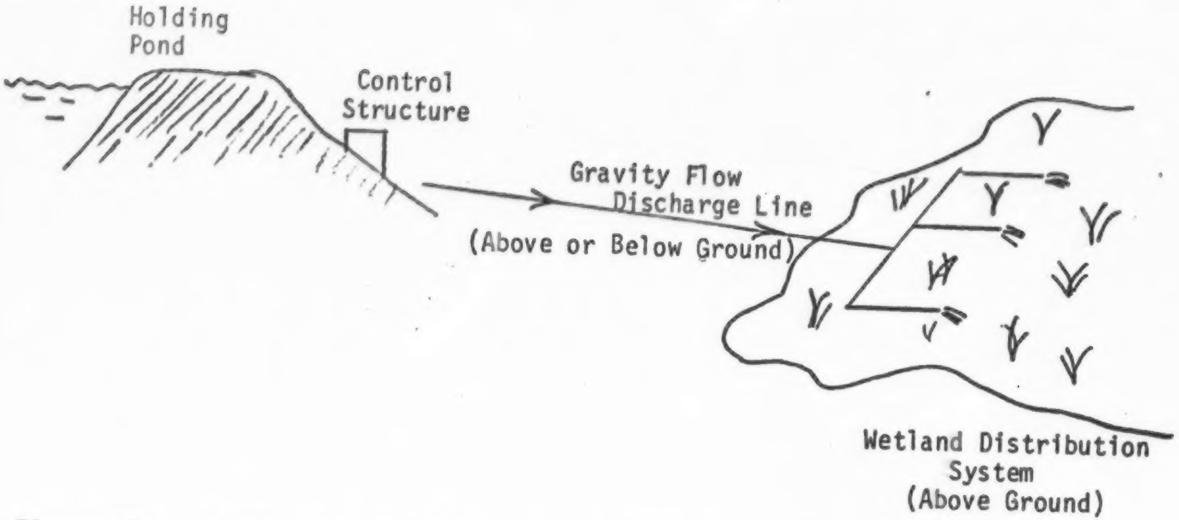

Holding Pond
Control Structure
Gravity Flow Discharge Line
(Above or Below Ground)
Wetland Distribution System (Above Ground)

Figure 38a. Simple, Gravity Flow Configuration for a Wetland Treatment System.

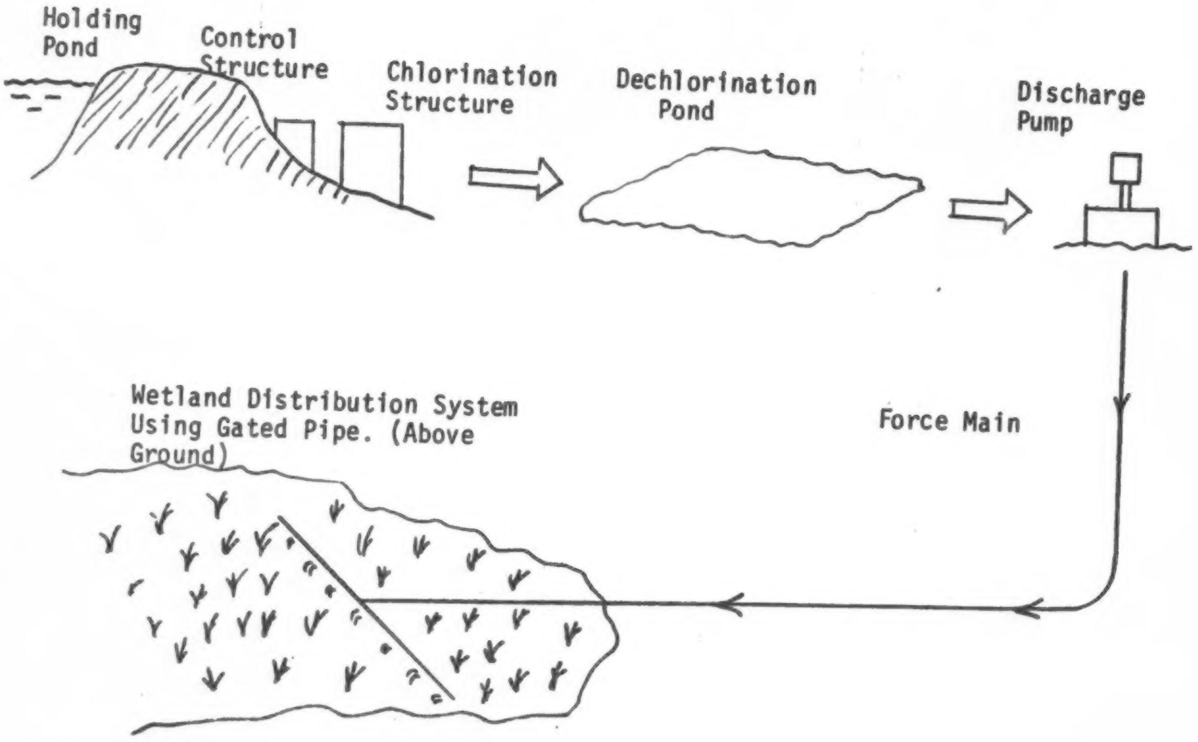

Holding Pond
Control Structure
Chlorination Structure
Dechlorination Pond
Discharge Pump
Force Main
Wetland Distribution System Using Gated Pipe. (Above Ground)

Figure 38b. Typical Configuration for a Wetland Treatment System Using Chlorination and Dechlorination, Pumps and Forcemains.

The design of artificial systems is very new and little performance data have been published. Spangler, et al. (24) have reported a study conducted at Seymour, Wisconsin, and Lakshman (15) has described the batch operations of the Humboldt treatment facility. Volunteer wetlands combining percolation and overland flow of surface waters have also been reported (86). Other projects are underway at Listowel, Ontario (97) and Arcata, California (30). The data from these demonstration systems should provide a basis for design of new artificial wetland systems, and answer some unresolved questions about the wetland treatment process in general.

OPERATIONS

Operation of a wetland treatment facility generally involves establishment of a discharge schedule and monitoring activities. In certain cases, biomass harvesting may also be considered. Due to the large number of unanswered questions about the wetland treatment process, many facilities are also involved in ongoing research. Funding for this work may come largely from external agencies, but the local community may also support scientific work which goes beyond routine monitoring.

The discharge schedule in northern climates is often seasonal. Wastewater is held in ponds during the winter and discharged only during the warm months, when plants, algae and microorganisms are most active. Controlled studies of winter discharge in carefully designed systems have not been completed. The discharge rate during the summer months is sometimes reduced when water levels are unusually high within the wetland due to heavy rains. This is done in an attempt to maintain a relatively constant residence time.

Monitoring usually consists of measurements of water quality in the wetland surface waters and ground waters. Outflows from the wetland should be sampled on a regular schedule, at least monthly. Inflows to the treatment area should be monitored, for they may also carry a significant quantity of nutrients and other substances. While preparation of component budgets is desirable, this can be extremely difficult at some sites. Measurements of the concentrations of nutrients and other wastewater components as a function distance from the irrigation point (transects) also provide valuable information on wetland performance. Monitoring of ground waters helps to establish the importance of infiltration/percolation.

The wastewater components of concern will vary from site to site. As a minimum, analyses of water samples should include nitrate-N, ammonium-N, total dissolved phosphorus or total phosphorus, chloride, pH, conductivity, and total suspended solids.

SECTION 7

WETLAND SYSTEM DESIGN: ANALYSIS

Performance of a proposed wetland treatment facility can be largely characterized by two types of calculations. The first type focuses upon the zone of rapidly decreasing concentrations. In this zone, consumption mechanisms are fast, and the removal rate of wastewater components is controlled by mass transfer through the surface water. The area of this zone, for constant wastewater discharge, should not change drastically with time. As the facility ages, certain nutrient consumption mechanisms exhibit saturation phenomena, and a second zone may begin to expand about the point of discharge. This second zone is characterized by sharply reduced removal rates for nutrients and presumably for other wastewater components; thus a greater total area is needed to perform the same degree of treatment. Therefore, the second type of calculations involves predicting the expansion rate of the "loaded" or "saturated" zone. The use of these concepts in the analysis of wetland system designs will be illustrated in the balance of this section.

MASS TRANSFER AND OVERLAND WETLAND FLOW

When wastewater is caused to flow over the surface of a wetland, nutrients and other pollutants are removed, primarily by delivery to and consumption at solid surfaces. Most homogeneous processes, that is, processes within the water itself, would occur to no greater or lesser extent than in the holding pond. However at the wetland surface, sorption and microbial processes may occur, as well as plant uptake. Algal and duckweed uptake may occur at the upper water surface. In any case, these additional processes (in comparison to a pond) require that each contaminant be transported to a bounding channel surface.

A typical relationship to describe this transport is:

$$N = kA\,(C_w - C_s) \qquad [7.1]$$

where N = contaminant transport rate, gm/day

k = mass transfer coefficient, m/day

A = area of surface, m^2

C_w = contaminant concentration in water, gm/m^3

C_s = contaminant concentration in water at channel surface gm/m^3

Such a relation is well established in the literature (38).

Such a rate expression must be coupled with mass balances for the contaminant and for the surface water to predict the distance or time for the removal of a dissolved substance. The mass balance for water (see Section 3) determines a relation between flows and depth, such as (3):

$$\frac{\partial}{\partial t}(\phi_s h) + \frac{\partial}{\partial x}(\phi h v) = p - e - i \qquad [7.2]$$

where ϕ = flow porosity across the wetland surface

ϕ_s = storage porosity

h = depth, m

t = time, days

x = distance, m

v = actual velocity, m/d

p = precipitation, m/d

e = evapotranspiration, m/d

i = infiltration, m/d

Such an expression contains two variables: depth and velocity; a further relation between these terms is necessary to define the hydrology. Two important cases will be considered: a natural wetland, in which fluid friction and the gradient of the soil surface determine a velocity-depth relation; and a diked wetland, in which depth is set by flow control at man-made structures.

In the former case, Kadlec, et al. (3) have determined several possible relations, of which the best for an unchanneled wetland appears to be:

$$v_s = C_n h^n \left(-\frac{dg}{dx}\right) \qquad [7.3]$$

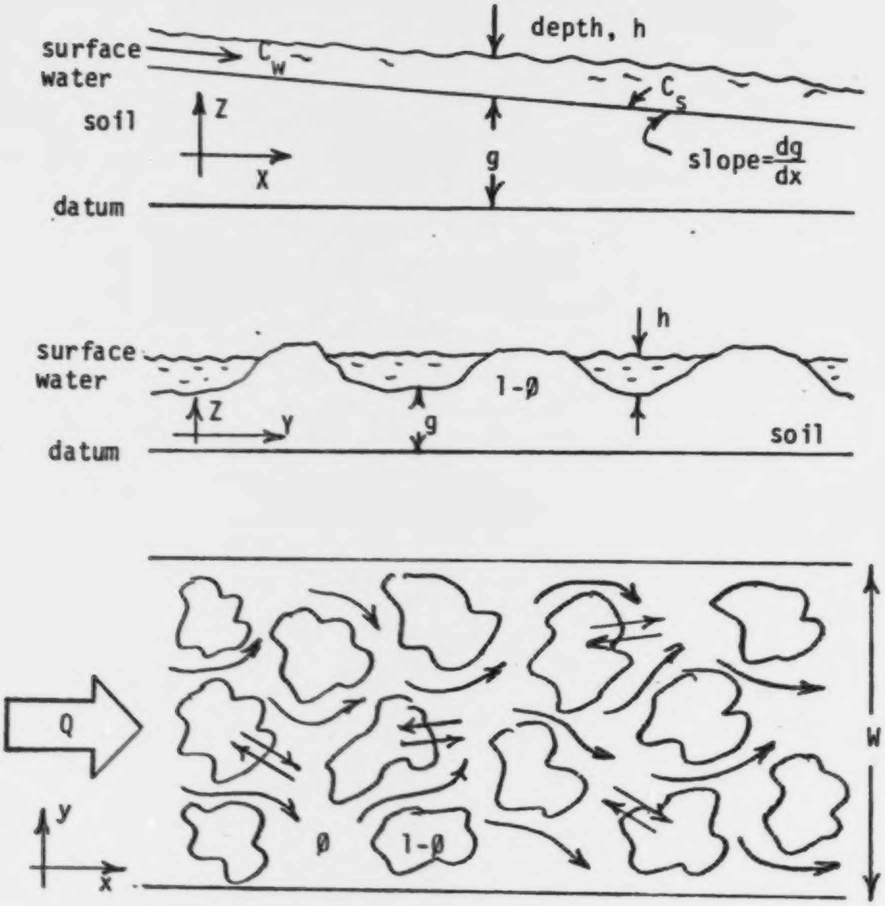
where v_s = superficial velocity, m/day

g = soil surface elevation, m

C_n = constant, $\frac{\text{m/d}}{(\text{m})^n}$

n = constant

Figure 39 defines the needed parameters. The gradient, $(\frac{dg}{dx})$, is typically small and perhaps nearly constant in the discharge zone; the exponent n appears to be equal to 2.0 for the Houghton Lake wetland (3).


depth, h
surface water
C_w
C_s
soil
Z
X
g
slope=$\frac{dg}{dx}$
datum
h
surface water
1-Ø
Z
y
g
soil
datum
Q
W
y
x
Ø
1-Ø

Q = flow rate

v = actual velocity

Ø = open area for flow(fraction)

v_s = Øv=superficial velocity

A=area=WX

ØA=active area

C_w=concentration in water

C_s=surface concentration

Figure 39. Mass Transfer and Flow Quantities.

In the case of a depth-controlled wetland, the depth is specified, and the mass balance alone determined velocity.

The contaminant mass balance is, for a linear-flow wetland

$$v_s h \frac{d\,C_w}{dx} = -\,k\phi(C_w - C_s) - i\,C_s + p\,C_p - e\,C_e \qquad [7.4]$$

where C_e is the contaminant concentration in evapotranspired water, gm/m^3

C_p is the contaminant concentration in precipitation, gm/m^3

(See Figure 39 for further definitions.)

At some upstream point, $x = 0$, the concentration will be known ($C_w = C_f$). Presumably this is either the discharge point; or, if the area around the discharge is saturated, it will be the outer edge of the inactive zone. For example, the zone of rapid removal should begin near the discharge line for denitrification (NO_3^- removal), since no saturation can occur. For an "older" facility, this rapid uptake zone for phosphorus would begin at a distance where saturation ends.

The mass transfer coefficient k is dependent on hydrodynamics, but in all cases described in the literature,

$$k = \gamma(hv)^s \qquad [7.5]$$

where γ and s are constants

Data presented earlier (Section 5) indicate $s = 1$ is appropriate for the Houghton Lake wetland.

These relations can be combined to predict performance in the zone of rapid removal. If consumption processes are sufficiently rapid, mass transport controls the removal. Consumption processes such as adsorption, are at equilibrium, and in most cases will produce "background" levels within the overlying water. The consequences of mass-transfer control for a few example cases will subsequently be explored.

Steady Friction-Controlled Sheet Flow in Linear Wetlands

Consumption processes shall be presumed fast enough that the surface concentration of the contaminant is constant at some value lower than that in the effluent reaching the rapid removal zone. The infiltration will be assumed to be zero. Precipitation and evapotranspiration will be presumed to be in balance and carry no contaminants. The wetland gradient will be assumed constant. The appropriate equations are then:

$$\frac{\partial}{\partial x}(\phi h v) = 0 \qquad [7.6]$$

$$v_s = \phi v = \beta h^n\left(-\frac{dg}{dx}\right) = \alpha h^n \qquad [7.7]$$

(constant superficial velocity)

$$v_s h \frac{dC_w}{dx} = -k\phi(C_w - C_s) \qquad [7.8]$$

$$k = \gamma(hv)^s \qquad [7.9]$$

The starting conditions required to determine the zone behavior are:

$$Q = Whv_s \text{ (flow = pumping rate)} \qquad [7.10]$$

$$C_w(x = 0) = C_f \qquad [7.11]$$

The system is "solvable" if we assume that the surface concentration is constant. The results are:

$$Q = \phi hv \qquad [7.12]$$

$$\phi v = \alpha h^n \qquad [7.13]$$

$$\ln \frac{C_w - C_s}{C_f - C_s} = -\frac{kx}{vh} \qquad [7.14]$$

$$k = \varepsilon v^{(s + \frac{s}{n})} \qquad [7.15]$$

$$k = \varepsilon v^w$$

where ε and w are constants

Generally, these variables are not the ones of greatest utility. Defining additionally residence time:

$$\theta = \frac{x}{v} \text{ (days)} \qquad [7.16]$$

and loading rate

$$L = \frac{Q}{\phi W x}\left(\frac{m^3/day}{active\ m^2}\right) \qquad [7.17]$$

The Equations 7.12, 7.13, 7.14 and 7.15 have a single solution for a given Q and C_w. For example, the effects of loading rate on the required area (or length) for a given removal percentage (above background) can be explored. For 90% removal, the logarithmic factor, B is

$$-B \equiv \ln \frac{C_w - C_s}{C_f - C_s} = \ln 0.1 = -2.3$$

and hence

$$B = \frac{kx}{vh} = 2.3 \qquad [7.18]$$

If one adopts the data developed from Houghton Lake:

$\phi = 0.25$

$n = 2$

$\alpha = 11{,}850 \ \mathrm{m}^{-1} \ \mathrm{d}^{-1}$

$s = 1$

$L = 0.267$ m/d

$\varepsilon = 1.43 \times 10^{-4} \ \mathrm{d}^{1/2}/\mathrm{m}^{1/2}$

then: $v = 267$ m/d

$x = 150$ m

$h = 0.15$ m

$\theta = 0.56$ d

It is interesting to note that for this wetland:

$$B = \frac{kx}{vh} = \frac{\varepsilon v^{3/2} x}{v(\frac{\phi v}{\alpha})^{1/2}} = \varepsilon \sqrt{\frac{\alpha}{\phi}}\, x \qquad [7.19]$$

Thus the required length is determined. In different terms, depth is given by

$$h = \left(\frac{B}{\varepsilon}\right)^{\frac{1}{s(n+1)}} \left(\frac{\phi}{\alpha}\right)^{\frac{1}{n}} L^{\frac{1}{s(n+1)}} \qquad [7.20]$$

or, for the Houghton Lake case,

$$h \propto L^{1/3} \qquad [7.21]$$

Also, since

$$\theta = \frac{x}{v} = \frac{h}{L} \qquad [7.22]$$

we have, for Houghton Lake:

$$\theta \propto L^{-2/3} \qquad [7.23]$$

The required length is given in general by:

$$x = \left(\frac{\phi}{\alpha}\right)^{\frac{1}{n}} \left(\frac{B}{\varepsilon}\right)^{\frac{1}{s}} L^{\frac{1-s}{s}} \qquad [7.24]$$

Steady Depth-Controlled Sheet Flow in Linear Wetlands

The previous equations (7.12, 7.14, 7.15, 7.16, 7.17) and assumptions apply in this situation. Equation 7.13 is not applicable; velocity is now controlled by means of depth control on an outlet structure. It must be noted, however, that the control depth must be in excess of that required by the friction law (Equation 7.8).

The new depth-length-loading relations are:

$$h = \left(\frac{\varepsilon}{B}\right)^{\frac{1}{w}} L^{\frac{w-1}{w}} x \qquad [7.25]$$

and further:

$$\theta = \left(\frac{\varepsilon}{B}\right)^{\frac{1}{w}} L^{-\frac{1}{w}} x \qquad [7.26]$$

For the Houghton Lake wetland,

$$w = s + \frac{s}{n} = 3/2$$

So: $h \sim L^{1/3} x$ [7.27]

and $\theta \sim L^{-2/3} x$ [7.28]

The effect of increased requirements for contaminant removal (increased values of $B = -\ln(\frac{C_w - C_s}{C_f - C_s})$) require an increase in length:

$$x \sim B^{1/w} \qquad [7.29]$$

for a fixed depth and loading. Since $w > 1$, length does not increase quite as fast as the logarithm of the fraction contaminant remaining.

If the wetland is operated at a depth, h_1, which must be greater than that for natural drainage, h_0, the predicted result is:

$$\frac{B_1}{B_0} = \left(\frac{h_0}{h_1}\right)^{\frac{s(n+1)}{n}} \qquad [7.30]$$

Based upon data obtained for the Houghton Lake treatment site, $s = 1$ and $n = 2$, the fraction removal decreases for a fixed wetland loading and length:

$$\frac{B_1}{B_0} = \left(\frac{h_0}{h_1}\right)^{3/2} \qquad [7.31]$$

Thus, for that site there is always a penalty for operating at depths greater than the natural drainage depth of the wetland.

These statements are based on "steady" operating conditions. A large rainfall would have the temporary effect of increasing depths in a flow controlled wetland and diluting the surface concentrations everywhere. The percentage removal would therefore decrease, in accordance with Equation 7.31. However, in a depth controlled wetland, the rainfall effect would depend on the exponent w:

$$B = \frac{kx}{hv} = \frac{\varepsilon v^w}{v} \cdot \frac{x}{h} \qquad [7.32]$$

For fixed x and h, $B \propto v^{w-1}$. An increase in removal would result for $w > 1$. In any case, since depths are likely to be in the vicinity of 15-20 cm (at least), it would take a huge rainfall to significantly alter the performance.

Steady Depth-Controlled Radial Overland Flow

The point discharge of wastewater to a wetland is a possibility, since it would require less distribution piping. There would be some form of depth control required, since it is unlikely that such a wetland would exist naturally. (See Figure 40).

A "saturated" zone will be presumed to exist to radius r_0, and r_1 will be the radius at which a specified reduction occurs. The radius of the wetland, r_2, must of course exceed r_1. The steady equations in this geometry are:

$$\frac{d}{dr}(2\pi r h v_s) = 0 \qquad [7.33]$$

$$v_s h \frac{dC_w}{dr} = -\phi k(C_w - C_s) \qquad [7.34]$$

$$k = \varepsilon v^w \qquad [7.35]$$

The starting conditions required are:

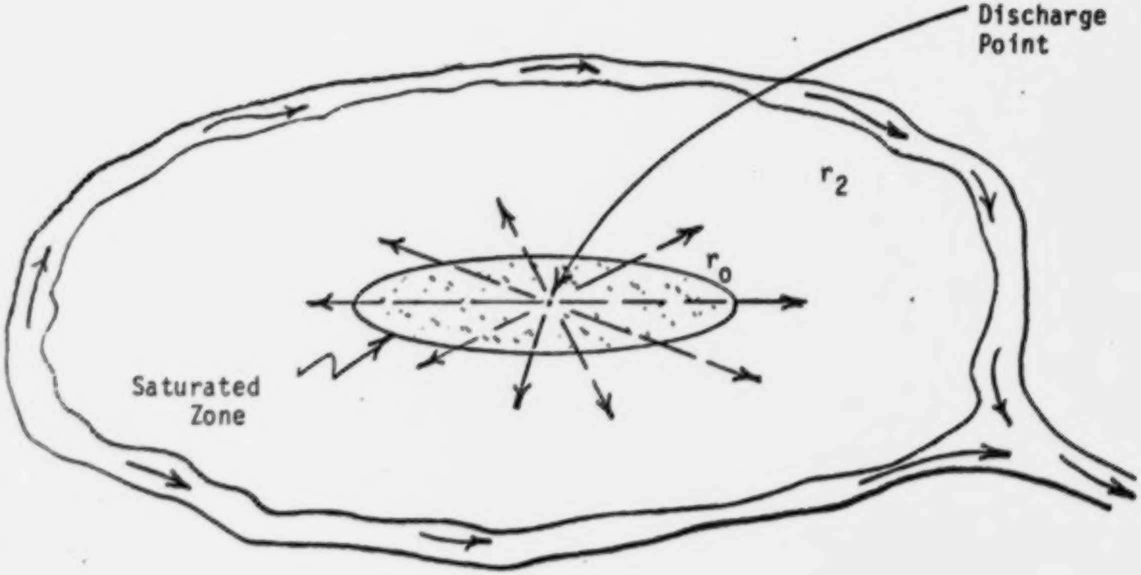

Discharge Point
r_2
r_o
Saturated Zone

Figure 40. Circular Geometry for Overland Flow.

$$Q = (2\pi r h v_s)_{r=r_c} \qquad [7.36]$$

$$C_w(r=r_0) = C_f \qquad [7.37]$$

$$Q = 2\pi r h \phi v \qquad [7.38]$$

$$B = -\ln \frac{C_w - C_s}{C_f - C_s} = \int_{r_0}^{r_1} \frac{k}{v\ h}\, dr \qquad [7.39]$$

$$k = \varepsilon\ v^w \qquad [7.40]$$

Using a loading variable defined as

$$L = \frac{Q}{\pi(r_1^2 - r_0^2)\phi}\ \frac{m^3/\text{day}}{\text{active } m^2} \qquad [7.41]$$

Hence:

$$v = \frac{(r_1^2 - r_0^2)L}{2\ rh} \qquad [7.42]$$

The resulting relation between depth, loading, and radius is:

$$h = G(\beta,w)\ (\tfrac{\varepsilon}{B})^{\frac{1}{w}}\ L^{1-\frac{1}{w}}\ x \qquad [7.43]$$

where $x = r_1 - r_0$ [7.44]

$$\beta = \frac{r_1}{r_0} \qquad [7.45]$$

$$G(\beta,w) = [(\tfrac{1+\beta}{2})^{w-1}\ \frac{(1-\beta^{2-w})}{(2-\ )}]^{\frac{1}{w}} \qquad [7.46]$$

This relation is nearly the same as Equation 7.25, but they differ by the factor $G(\beta,w)$. For the specific case of Houghton Lake, $w = 3/2$. The factor $G(\beta,w)$ is shown in Figure 41 for this case. For comparable depths and loadings, the radial system requires greater distances for the same degree of removal under mass transfer control. For an unsaturated wetland, the factor is 26% larger; and this decreases to break-even at $r_0/r_1 = 0.91$.

Thus, no advantage is available until a very large saturated zone has developed.

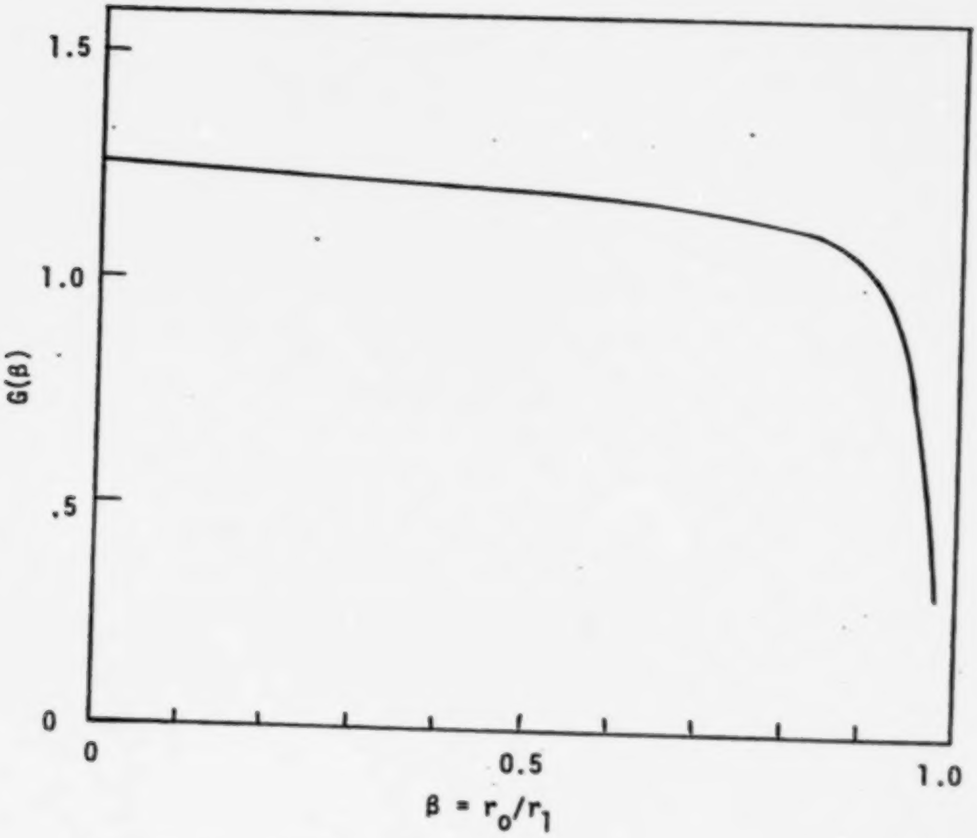


Figure 41. Length Factor for Radial Wetland Flow Versus Linear Flow. For the Case w = 3/2.

The Effect of Infiltration

It is possible that some water infiltrates into the soil in the sorption zone. This clearly shortens this zone by reducing the overland flow component. The magnitude of this effect is large.

The appropriate steady mass balance equation for water in a linear system is:

$$\frac{dQ}{dx} = -iW \qquad [7.47]$$

where W = wetland width, m

where precipitation and evapotranspiration effects are presumed to cancel. The mass balance for a contaminant is:

$$\frac{d(C_W Q)}{dx} = -kW\phi(C_W - C_s) - i\,C_s\,W \qquad [7.48]$$

At some starting distance, the overland flow and concentration will be known. This flow will be reduced by the amount which infiltrates in the saturated zone. The concentration will be the same as in the wastewater feed if no other uptake occurs in that zone. Thus at $x = 0$, $C_W = C_S$ and $Q_1 = \varepsilon Q_0$, where Q_0 = wastewater flow and ε is the fraction remaining at the beginning of the fast removal zone. These equations may be solved to give:

$$Q = Q_1 - i\,x\,W \qquad [7.49]$$

$$x = \frac{Q_1}{i\,W}\left(1 - e^{-\frac{Bi}{ak\phi}}\right) \qquad [7.50]$$

where: $$B = \ln\frac{C_f - bC_s}{C_W - bC_s} \qquad [7.51]$$

and $$a = 1 + \frac{i}{k\phi} \qquad [7.52]$$

Recalling earlier results without infiltration:

$$x_{old} = \frac{Q_o}{W\phi L} \qquad [7.53]$$

and requiring the same removal $B = k/L$, we find the enhancement ratio to be:

$$\frac{x}{x_{old}} = \xi\,\frac{\phi L}{i}\left(1 - e^{-\frac{i}{a\phi L}}\right) \qquad [7.54]$$

For example, if transport by infiltration equals that by mass transfer ($i = k\phi$, $a = 2$), and infiltration is one half the loading rate ($i/\phi = L/2$), then:

$$\frac{x}{x_{old}} = 0.442\xi \qquad [7.55]$$

So even at the outset of irrigation ($\xi = 1$), the sorption zone would be significantly reduced. In this comparison, it is assumed that $C_s = 0$, because the value of B for this case is:

$$B = \ln \frac{C_f - bC_s}{C_w - bC_s} \qquad [7.56]$$

where $$b = \frac{2}{a} - 1 \qquad [7.57]$$

The case of negative infiltration (wetland discharge) is governed by Equation 7.47 with $i < 0$, a zero groundwater concentration, and:

$$\frac{d(C_w Q)}{dx} = kW\phi(C_w - C_s) \qquad [7.58]$$

Also, Q at $x = 0$ is $Q_1 = \xi Q_0$, $\xi < 1$.

Thus, $$Q = Q_1 + (-i)xW \qquad [7.59]$$

and $$x = \frac{Q_1}{(-i)W}\left(e^{\frac{B(-i)}{ak\phi}} - 1\right) \qquad [7.60]$$

where $$B = \ln \frac{C_f}{C_w} \qquad [7.61]$$

For the case of $B = k/L$ from the no-infiltration comparison case,

$$\frac{x}{x_{old}} = \xi \frac{\phi L}{(-i)}\left(e^{\frac{(-i)}{a\phi L}} - 1\right) \qquad [7.62]$$

For example, if $a = 1/2$ and $i/\phi = -L/2$ (exfiltration is 1/2 of mass transfer and loading) we have:

$$\frac{x}{x_{old}} = 3.44\xi \qquad [7.63]$$

This penalty for discharging wetlands increases dramatically as discharge $(-i)/\phi$ approaches mass transfer, k. When equal, treatment no longer occurs.

CAPACITY CONSIDERATIONS: AREAL EXPANSION OF THE LOADED ZONE

The addition of nutrients to a natural or newly constructed wetland will cause a zone of increased vegetative growth to appear. This zone will expand with time until either the permanent capacity of the zone equals the loading rate, or the loaded zone reaches the boundaries of the wetland. The mathematical description of the advance of such a loaded zone for each substance of interest, such as phosphorus, consists of a mass balance on the zone and the rates at which the substance is taken up by the stationary ecosystem. These uptake rates fall in three general categories. The first of these is a permanent binding of the substance in question, or a gaseous loss to the atmosphere, such as denitrification. In these cases, a component is permanently removed from surface waters. A second general category consists of an increase in the adsorbed quantity of the substance; which is the physical or chemical binding of the substance to the soil substrate within the wetland. Such processes are known to occur for phosphorus and ammonia, for example. The third general category of nutrient consumption is storage in an expanding biomass compartment.

Other uptake/release processes also occur in the wetland ecosystem at rapid rates. An example of this is the uptake of phosphorus and nitrogen by algae. These algae grow during the summer months, die, and contribute a certain amount of algal litter to the sediment layers within the wetland. These algal sediments decompose and re-release the nitrogen and phosphorus that was incorporated in the biomass. This process is fairly rapid in the summer months, and if one considers only year to year variations in area, this process is too fast to be noticeable. There is little net effect of such rapid cycling. A second type of rapid cycling of nutrients is the uptake by vascular plants. With their senescence and death, the leaching of nitrogen, phosphorus, and carbon from the biomass, directly back to the water column, occurs every year. This cycle is also too fast to be considered in a framework that is geared to predicting the change of the affected area from year to year. Thus, in the model development which follows, only those processes which persist for a period greater than one growing season are considered as long term consumers for nutrients. Put in another way, all quantities are expressed as rates, but these are averages over the period of one year or longer.

To make this model more tractable, it is assumed that sufficient residence time is provided so that all materials can reach the plant and soil community. The zone of mass transfer limitation of the removal rate is neglected. This idealization results in a sharp line of demarcation between the loaded and unloaded zones. This is not entirely accurate since according to the principles of mass transfer a zone must be present in which nutrient levels within surface water are decreasing.

The Mass Balance for the Expanding Loaded Zone

If one considers the increase of a "saturated" zone of area A (m^2) due to the addition of nutrient-laden waters as illustrated in Figure 42, this area can be calculated from a mass balance for a given material, such as phosphorus. In terms of the possible sinks, the equation in words is:

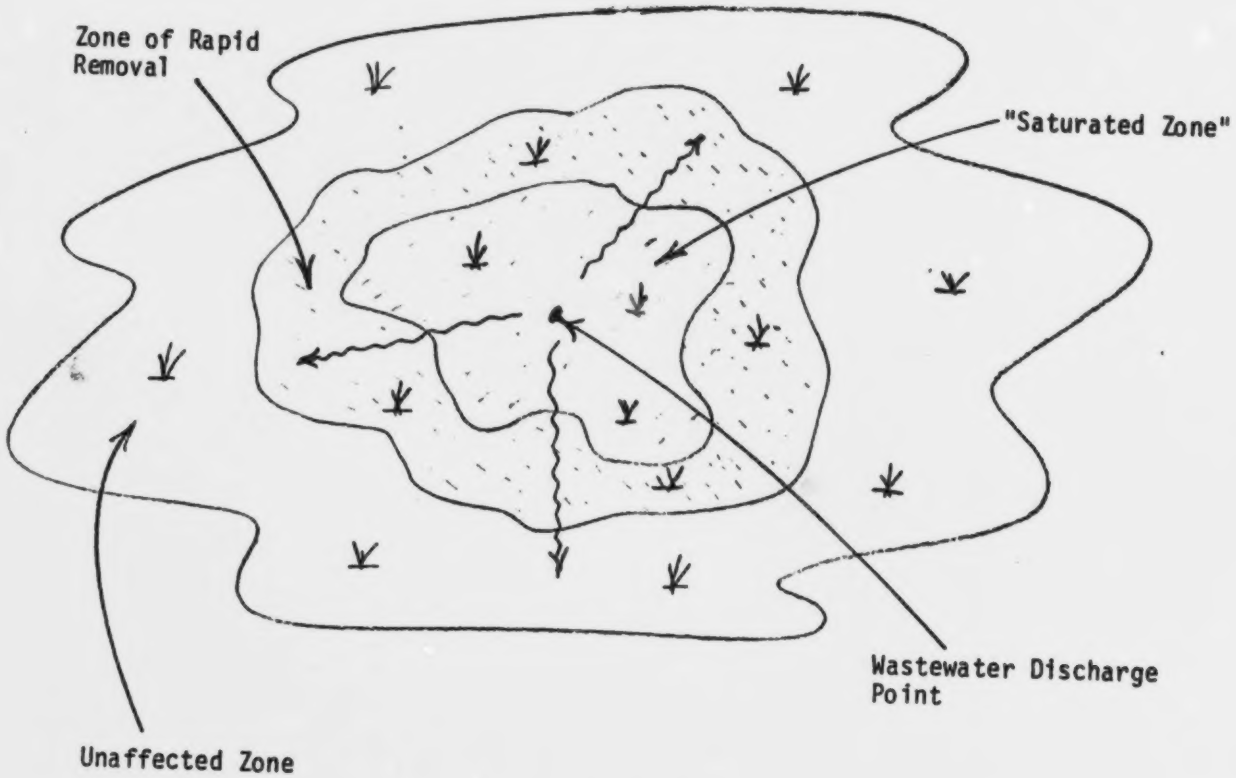

Zone of Rapid Removal
"Saturated Zone"
Wastewater Discharge Point
Unaffected Zone

Figure 42. Schematic of the Zone of Affected Soil and Biomass.

$$\text{addition rate} = \text{sorption rate} + \text{permanent removal rate} + \text{temporary binding rate} + \text{discharge rate.}$$

We next develop reasonable expressions for each term. In symbols, we have:

$$\text{addition rate} = Q\,C_i \qquad [7.64]$$

where Q = average annual wastewater addition rate, m^3/yr

C_i = mass average concentration of contaminant or nutrient in influent wastewater, gm/m^3

In this and all following terms, rates are incremental: they are those in excess of the background rates and concentrations.

The concentration of a contaminant in the overlying water within the affected zone depends somewhat on location. Only permanent removal mechanisms operate in the older regions of the affected zone, while both temporary and permanent mechanisms operate in the newer regions. Figure 43 shows a possible concentration profile produced in response to such effects.

The average water concentration, C_ℓ, is thus less than the wastewater concentration ($C_\ell < C_i$). A decrement of 10-20% for a new wetland system may be proper; a lesser decrement would be appropriate for older systems.

Sorption Mechanisms--

The sorption of a nutrient such as phosphorus has been found to reach equilibrium in fairly short periods of time, on the order of several days. Consequently, the description of sorption on the soil will be presumed to be the loading of an upper soil horizon with an equilibrium amount of the adsorbing constituent. Of course, this may be zero for some constituents such as nitrate; however, it is fairly important for constituents such as orthophosphate. Penetration to deep soil horizons by diffusion is slow because of the saturation of the overlying horizons, and the lengthening diffusional path required for the transport of the material to the deeper zones. When coupled with possible soil accretion rates at the surface, such penetration does not occur easily in a perched wetland situation. Therefore, for the perched wetland, the rate of sorption of a sorbable constituent is given by:

$$\text{sorption rate} = \frac{d(A\,M_A)}{dt} \qquad [7.65]$$

where M_A = amount sorbed per unit area, gm/m^2

A = area, m^2.

In turn, the equilibrium amount sorbed typically is calculable in terms of an adsorption isotherm, such as

$$M_A = kz_f\,C_\ell \qquad [7.66]$$

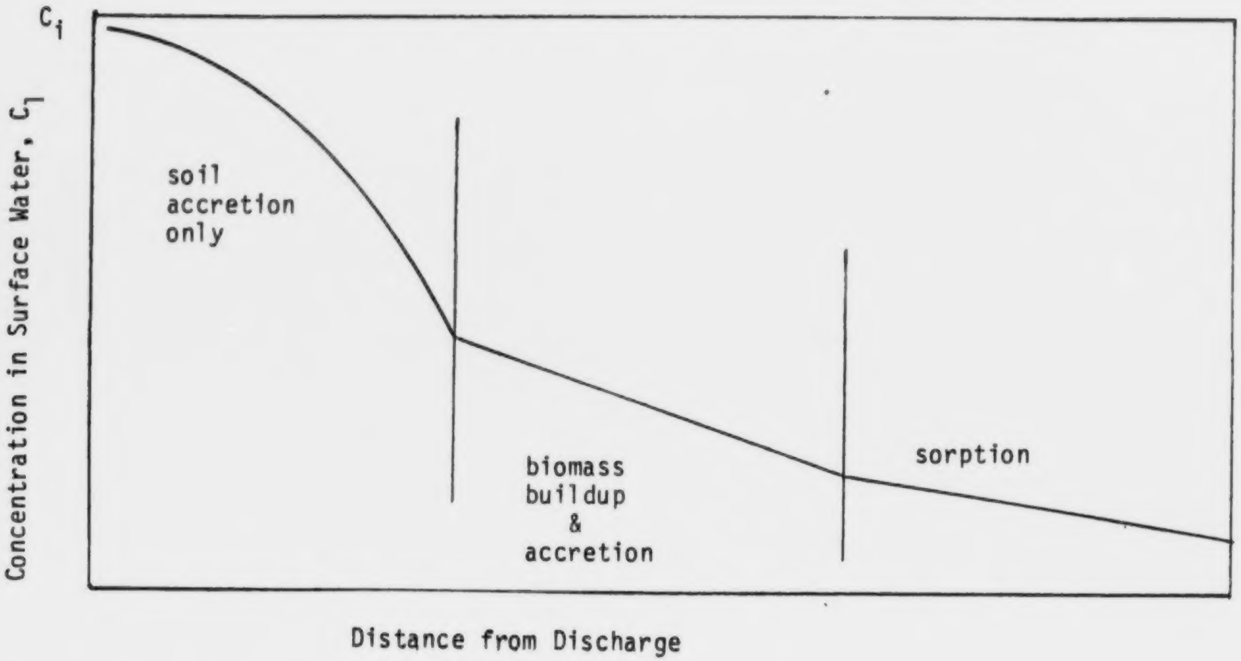


Figure 43. Concentration Profiles in a Possible Wetland Treatment Scenario.

where k = sorption equilibrium constant $(\text{gm/m}^3)_s/(\text{gm/m}^3)_\ell$

C_ℓ = concentration in surface water, gm/m^3

z_f = sorption depth, m

The amount of interstitial constituent is normally small, thus the net effect for constant y is:

$$\text{sorption rate} = kz_f\, C_\ell \frac{dA}{dt} \qquad [7.67]$$

In contrast to purely diffusional processes, the existence of a downward component of water flow (recharge or infiltration) can carry contaminants to "fresh" sorption sites at relatively fast rates. The material not immobilized may continue on to groundwater. Thus, downflow constitutes a process for "permanent" removal from surface waters, and it is an areal term (proportional to area). Diffusion and sorption for the perched wetland are also areal, but shut down as the square root of time. Combining the two effects gives:

$$C_a \frac{dz_f}{dt} = \frac{D(C_\ell - 0)}{f} + i\, C_\ell \qquad [7.68]$$

$$\begin{array}{c} \text{downward sorption} \\ \text{front movement} \end{array} = \begin{array}{c} \text{diffusional} \\ \text{additions} \end{array} + \begin{array}{c} \text{bulk flow} \\ \text{additions} \end{array}$$

where C_a is the adsorbed concentration, $\text{gm/m}^3 = kC_\ell$

i is the downward velocity, m/yr

Here it is assumed that there is no "leakage" to groundwater, and that a penetration model is valid.

Diffusion would likely be small, thus:

$$i \gg \frac{D}{z}$$

Since $D \sim 10^{-5}\ \text{cm}^2/\text{s}$, a percolation rate of 10^{-6} cm/s (0.864 mm/day) will cause equal effects at a depth of 10 cm.

In the case of a perched wetland, $i = 0$, penetration proceeds only by diffusion. The depth of the sorption front as a function of exposure time can be determined from

$$kC_\ell \frac{dz_f}{dt} = \frac{D(C_\ell - 0)}{z_f} \qquad [7.69]$$

$$z_f(0) = 0$$

which gives

$$z_f^{\,2} = \frac{Dt}{2k} \qquad [7.70]$$

or

$$z_f = \sqrt{\frac{D}{2k}}\ \sqrt{t} \qquad [7.71]$$

The amount sorbed per unit area at any place is then

$$M_A = kC_\ell\, z_f = C_\ell\sqrt{\frac{Dk}{2}}\ \sqrt{t} \qquad [7.72]$$

Adding up all such contributions over the affected zone,

$$\text{total amount sorbed} = \int_0^A C_\ell\sqrt{\frac{Dk}{2}}\ \sqrt{t-\tau}\ dA \qquad [7.73]$$

where τ = zone arrival time.

Converting to the time variable,

$$\text{total amount sorbed} = \int_0^t C_\ell\sqrt{\frac{Dk}{2}}\ \sqrt{t-\tau}\ \frac{dA}{d\tau}\, d\tau \qquad [7.74]$$

The total sorption rate is then:

$$\text{total sorption rate} = \frac{d}{dt}\left[\int_0^t C_\ell\sqrt{\frac{Dk}{2}}\ \sqrt{t-\tau}\ \frac{dA}{d\tau}\, d\tau\right]$$

$$= C_\ell\sqrt{\frac{Dk}{2}}\left\{\sqrt{t-\tau}\ \frac{dA}{dt} + \int_0^t \frac{1}{2}\ \frac{1}{\sqrt{t-\tau}}\ \frac{dA}{d\tau}\, d\tau\right\} \qquad [7.75]$$

Due to the complexity of this term, the total sorption rate is approximated by choosing a constant, average z_f-value.

Alternatively, if downflow predominates as in the case of recharge ($i \gg D/z_f$), it follows that:

$$z_f = \frac{it}{k} \qquad [7.76]$$

This means that the sorption rate is independent of position, and therefore:

$$\text{total rate of sorption} = \frac{d}{dt}[A\ z_f\ kC_\ell] = iC_\ell A + iC_\ell\ t\ \frac{dA}{dt} \qquad [7.77]$$

The first term represents an areal removal rate which continues indefinitely; the second portion represents the addition of new sorption/downflow area. This second part becomes zero at steady state. Solutions to this problem are difficult and must be done by numerical methods.

Long-term Consumption Mechanisms--

Permanent loss or immobilization rates occur due to processes such as soil building, denitrification, and the development of a woody herbaceous material which does not decompose for long periods of time. The harvesting of biomass also falls in this category. All such permanent removals have the feature that their annual rate is proportional to the area of the loaded zone, that is such processes occur above background levels only in the area of influence. Further, these mechanisms do not saturate as does sorption; and therefore, these rates are proportional to the entire area of the affected zone. In symbols, the following breakdown results:

$$\text{permanent removal rate} = r_s C_s A + r_A A + r_w A x_w + r_H x_H A \qquad [7.78]$$

r_s = excess average annual soil accretion rate, m/yr

C_s = contaminant concentration in new soil, gm/m^3

r_A = excess average annual rate of loss to atmosphere, gm/m^2/yr

r_w = excess average annual woody stem accumulation rate, gm/m^2/yr

x_w = fraction contaminant in woody stems

r_H = average annual harvest rate, gm/m^2/yr

x_H = fraction contaminant in harvested biomass

It is assumed that the expansion of the loaded zone during any given irrigation season does not result in any immediate expansion of the zones of harvest, soil accretion, or woody stem growth. Rather, only sorption is considered to be active in the newly-formed loaded zone. We have chosen to call woody biomass formation a permanent mechanism, since the decomposition time scale is quite long.

Expansion of Biomass--

The description of the dynamic binding of a contaminant within the newly grown biomass pool requires a bit more sophistication. Increased growth of plants produces an increased amount of litterfall, and hence the entire biomass pool within the loaded zone increases. The building of this new material requires the incorporation of some of the contaminant into that new material. However, after sufficient time has elapsed, this process stops, since no further increases in total biomass can occur. Thus the interior portions of the loaded zone are no longer as effective in removing contaminants from the passing water. The outer fringes retain higher consumption rates for a number of years, as long as biomass is still accumulating.

Choosing the point in time for annual inventory as late fall, all new additional biomass is present in the form of wood, litter, and standing dead. Some of the increased growth of biomass has already been leached and otherwise decomposed, leaving only a fraction of the peak standing crop in the form of litter and standing dead. This fast cycling loop of nitrogen, phosphorus and other contaminants back to the surface waters can be neglected as being too fast to notice on a year to year basis. Thus, quantification of this dynamic immobilization of contaminants within the new pool of biomass requires a description of the rate of litter accumulation. This rate must then be integrated over the entire area of interest.

At any one location, the annual budget for excess litter biomass can be written as:

$$\frac{dM}{dt} = F - \alpha_d M \qquad [7.79]$$

where M = amount of excess litter, gm/m^2

F = average annual excess litter fall, gm/m^2/yr

α_d = average annual specific litter decay rate, yr^{-1}

at the time of arrival of the nutrients, this litter excess is zero: $M(0) = 0$. Solving this results in:

$$M = \frac{F}{\alpha_d}(1 - e^{-\alpha_d t}) \qquad [7.80]$$

and the excess litter accumulation rate is:

$$\frac{dM}{dt} = Fe^{-\alpha_d t} \qquad [7.81]$$

In a region which received wastewater with residual nutrients at a time τ, this rate is:

$$\frac{dM}{dt} = Fe^{-\alpha_d (t-\tau)} \qquad [7.82]$$

Summing over the entire loaded zone, the average annual excess litter accumulation rate, r_L gm/yr, is:

$$r_L = \int_0^A Fe^{-\alpha_d(t-\tau)} dA \qquad [7.83]$$

changing variables from A to t:

$$r_L = \int_0^t Fe^{-\alpha_d(t-\tau)} \frac{dA}{d\tau} d\tau \qquad [7.84]$$

For a contaminant of interest, the removal rate is:

$$\text{temporary binding rate} = r_L x_L = x_L \int_0^t Fe^{-\alpha_d(t-\tau)} \frac{dA}{d\tau} d\tau \qquad [7.85]$$

where x_L = fraction contaminant in litter, (assumed constant).

Closure--

All of the above may be combined to form the mass balance for the expanding loaded zone:

$$QC_i = kz_f C_\ell \frac{dA}{dt} + (r_s C_s + r_A + r_w x_w + r_H x_H)A$$

$$+ x_L \int_0^t Fe^{-\alpha_d(t-\tau)} \frac{dA}{d\tau} d\tau \qquad [7.86]$$

for which A(0) = 0 (starting). If permanent terms are combined:

$$R_p = r_s C_s + r_A + r_w x_w + r_H x_H \qquad [7.87]$$

where R_p = total average annual excess removal rate, gm/m^2/yr

then

$$QC_i = kz_f C_\ell \frac{dA}{dt} + R_p A + x_L \int_0^t Fe^{-\alpha_d(t-\tau)} \frac{dA}{d\tau} d\tau \qquad [7.88]$$

It is noted that the final, steady-state area is given as:

$$A^* = \frac{QC_i}{R_p} \qquad [7.89]$$

To simplify notation, we define

$$f \equiv \frac{A}{A^*} \quad \text{(fraction of final area)} \qquad [7.90]$$

$$\theta \equiv \alpha_d t$$

$$T \equiv \alpha_d \tau$$

(time in terms of decomposition time) [7.91] [7.92]

$$a_1 \equiv \frac{Fx_L}{R_p} \qquad \frac{\text{litter fall rate}}{\text{permanent removal rate}} \tag{7.93}$$

$$a_2 \equiv \frac{kz_f C_\ell \alpha}{R_p} \qquad \frac{\text{sorption rate}}{\text{permanent removal rate}} \tag{7.94}$$

which then gives:

$$1 = f + a_1 \int_0^\theta e^{-(\;-T)} \frac{df}{dT} + a_2 \frac{df}{d\theta} \tag{7.95}$$

$$f(0) = 0$$

This equation may be solved in any one of several ways. Results are the areal expansion of the loaded zone in terms of two groups of parameters, a_1 and a_2. As an illustration, consider the following parameter set for phosphorus:

$\alpha_d = 0.25\ \text{yr}^{-1}$

$r_s = 4 \times 10^{-3}$ m/yr

$C_s = 150\ \text{gm/m}^3$ (0.15% dry weight)

$r_A, r_W, r_H = 0$

$F = 300\ \text{gm/m}^2/\text{yr}$

$x_L = 0.002$ (0.2% dry weight)

$$a_1 = \frac{(300)(0.002)}{(0.6)} = 1.0$$

$$k = 32\left(\frac{\text{gm}}{\text{m}^3}\right)_s / \left(\frac{\text{gm}}{\text{m}^3}\right)_w$$

$z_f = 0.05$ m

$C_i = 1.5\ \text{gm/m}^3$

$C_\ell = 1.5\ \text{gm/m}^3$

$a_2 = 1.0$

$Q = 100{,}000\ \text{m}^3/\text{yr}$ (26.4×10^6 gallons/yr)

$A^* = 250{,}000\ \text{m}^2$ (25 hectares)

$R_p = 0.6\ \text{mg/m}^2\text{/yr}$

Figure 44 shows the progression of the loaded area from zero to its final value of 25 hectares, expressed as a fraction. For comparison, if harvest is added, for which:

$r_H = 1000\ \text{gm/m}^2\text{/yr}$

$x_H = 0.002$

Then the value of $R_p = 2.0\ \text{gm/m}^2\text{/yr}$ and an ultimate area, $A^* = 75{,}000\ \text{m}^2$ (7.5 ha), results. It is further presumed that harvest prevents excess litter buildup, hence F = 0. This speeds the process of reaching the final loaded area, as shown in Figure 44.

The relative importance of the different removal mechanisms can be seen in Figure 45. Each (fractional) rate term is plotted separately, and they must add to the application rate (fraction = 1.0). Initially, the entire consumption of wastewater components is due to sorption. Soil and litter formation quickly become important; but only the long-term consumption mechanisms remain operative after a few decades.

Breakthrough: Insufficient Area

A wetland may prove smaller than required for complete removal of nutrients to natural background levels. This condition may develop after a number of years. The mass balance equation (and solution) up to the time of breakthrough is unaltered. Thereafter, no further sorption can occur, no more area is added to the biomass pool, and the permanent removal mechanisms are fixed at the current level. A certain amount of excess litter accumulation continues to occur within the wetland, predominantly at the outer edges. The mass balance equation for these new circumstances reflects these changes, plus the addition of a discharge rate term:

$$QC_i = R_p A + e^{-\alpha_d (t-t^*)} \left[x_L F \int_0^{t^*} e^{-\alpha_d (t-\tau)} \frac{dA}{d\tau}\, d\tau \right] + Q_D C_D \qquad [7.96]$$

where t^* = breakthrough time, yr

Q_D = discharge rate, $\text{m}^3\text{/yr}$

C_D = contaminant concentration in wetland discharge, gm/m^3

In dimensionless terms:

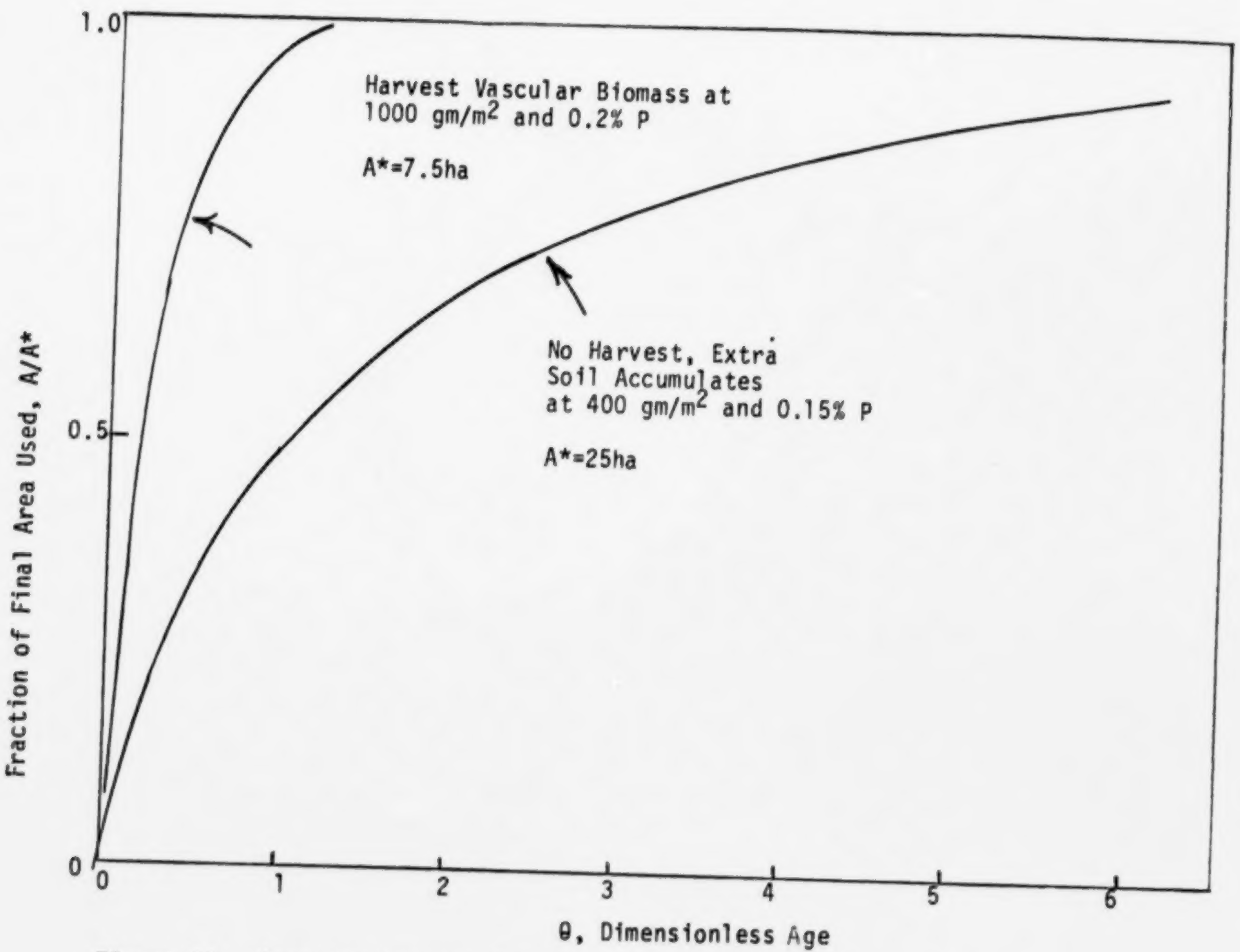


Figure 44. Area Requirement for a Typical Wetland Treatment System (See Text for Data Used).

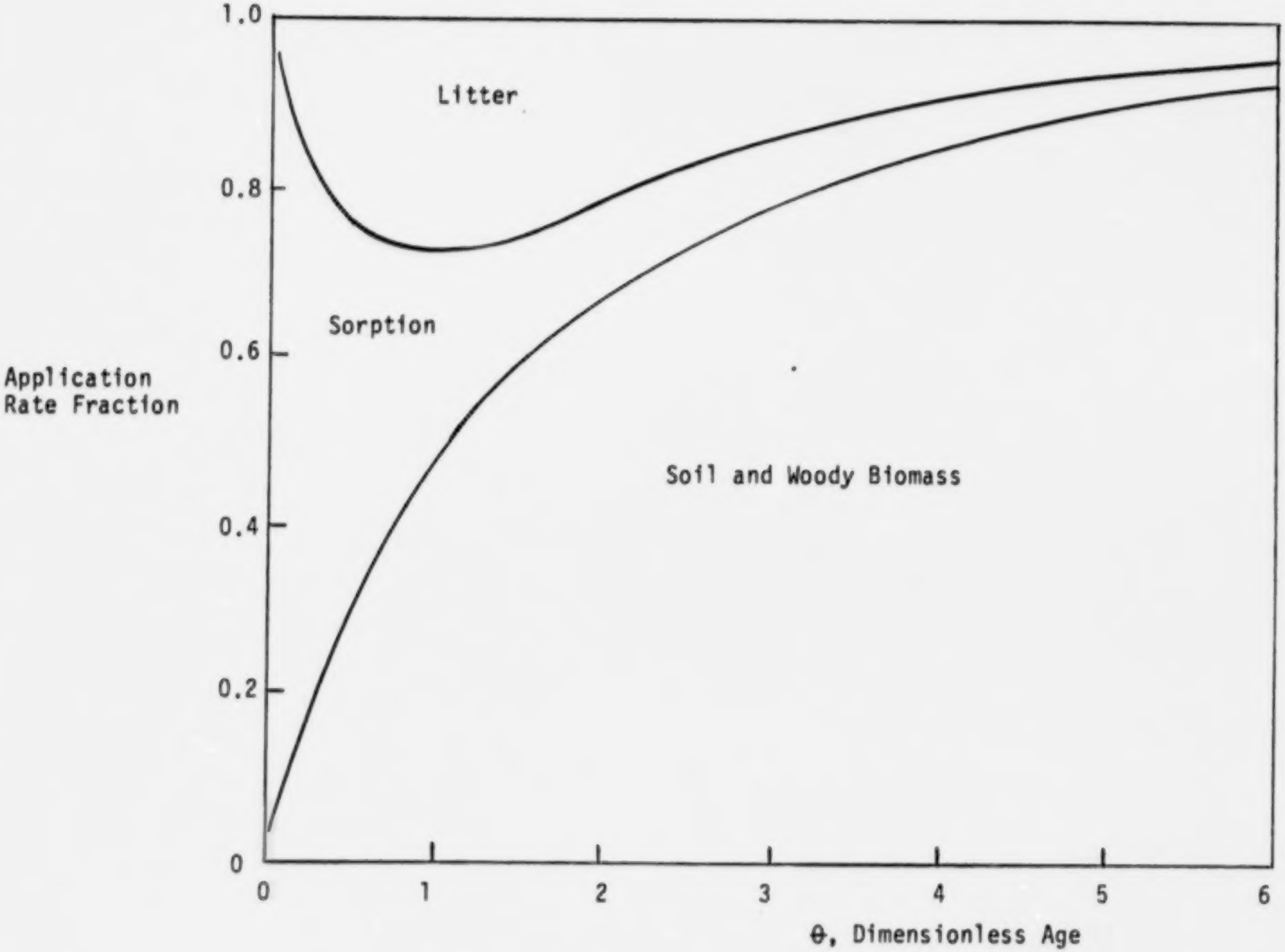


Figure 45. Phosphorus Uptake Rates for a Typical Wetland.
Application Rate: 150 kg P/yr
Ultimate Area Req'd: 25 ha
See Text for Data Used.

$\alpha \leq \theta \leq \theta$

$$1 = f + a_1 \int_0^{\theta} e^{-(\theta - T)} \frac{df}{dt} dT + a_2 \frac{df}{d\theta} \qquad [7.97]$$

$$f(0) = 0$$

$\theta \geq \theta$

$$1 = f + a_1 e^{-(\theta - \theta^*)} \left[\int_0^{\theta^*} e^{-(\theta^* - T)} \frac{df}{dT} dT \right] + d \qquad [7.98]$$

where $$d = \frac{Q_{DC_D}}{QC_i} = \text{fractional contaminant discharge.} \qquad [7.99]$$

If the same example wetland data set is chosen as in the previous example, and in addition we specify the area available to be 16.5 ha, then we will have breakthrough at 8 years ($\theta = 2$). Of the applied nutrient, some now exits the wetland. For $Q_D = 1.2\ Q$ (some dilution due to runoff and rain), the concentration is plotted in Figure 46.

The rates of uptake due to litter building, sorption, and permanent removal are shown for this case in Figure 47. The ultimate fraction discharged of contaminant (phosphorus) is equal to the fraction of missing required area.

Extension to other Contaminants

The foregoing examples have been worked out for phosphorus as a controlling contaminant. However, it may also be applied with suitable parameter values to nitrogen or any other contaminant for which information is available on the processes described above. The constraints under which the foregoing has been constructed bear further elaboration. Processes which take place on a time scale less than one year or greater than 100 years have been neglected in this model. Thus rapid internal cycling through algae does not play a role, and the immobilization of materials within woody material is treated as a permanent sink for those materials. In addition, it must be mentioned that the controlling wetland size may not be governed by the capacity of the wetland, but rather by the required residence time and depth constraints discussed in the previous section. This is especially true in the case of a harvested wetland, for which the areal requirements may be much smaller than for an unharvested wetland. This may mean that the mass transfer restriction will predominate over capacity restrictions in some cases. It is also presumed throughout the foregoing that the quality of the incoming wastewater is sufficiently good so that a viable ecosystem survives and indeed thrives in the presence of added nutrients.

Modifications must be made for contaminants which are not growth-controlling. Further, the foregoing examples do not apply in their entirety to wetlands that are in the recharge or discharge mode.

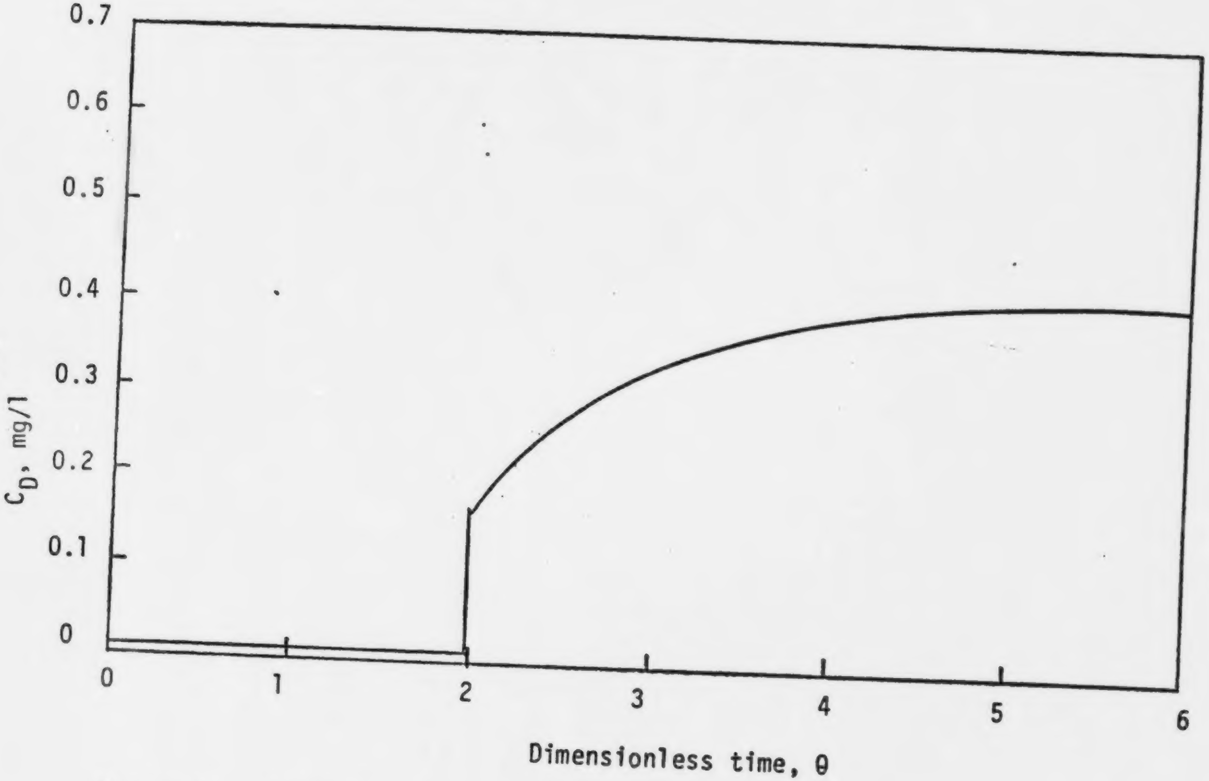


Figure 46. Breakthrough in a Wetland with 66% of the Required Capacity. (See text for data used)

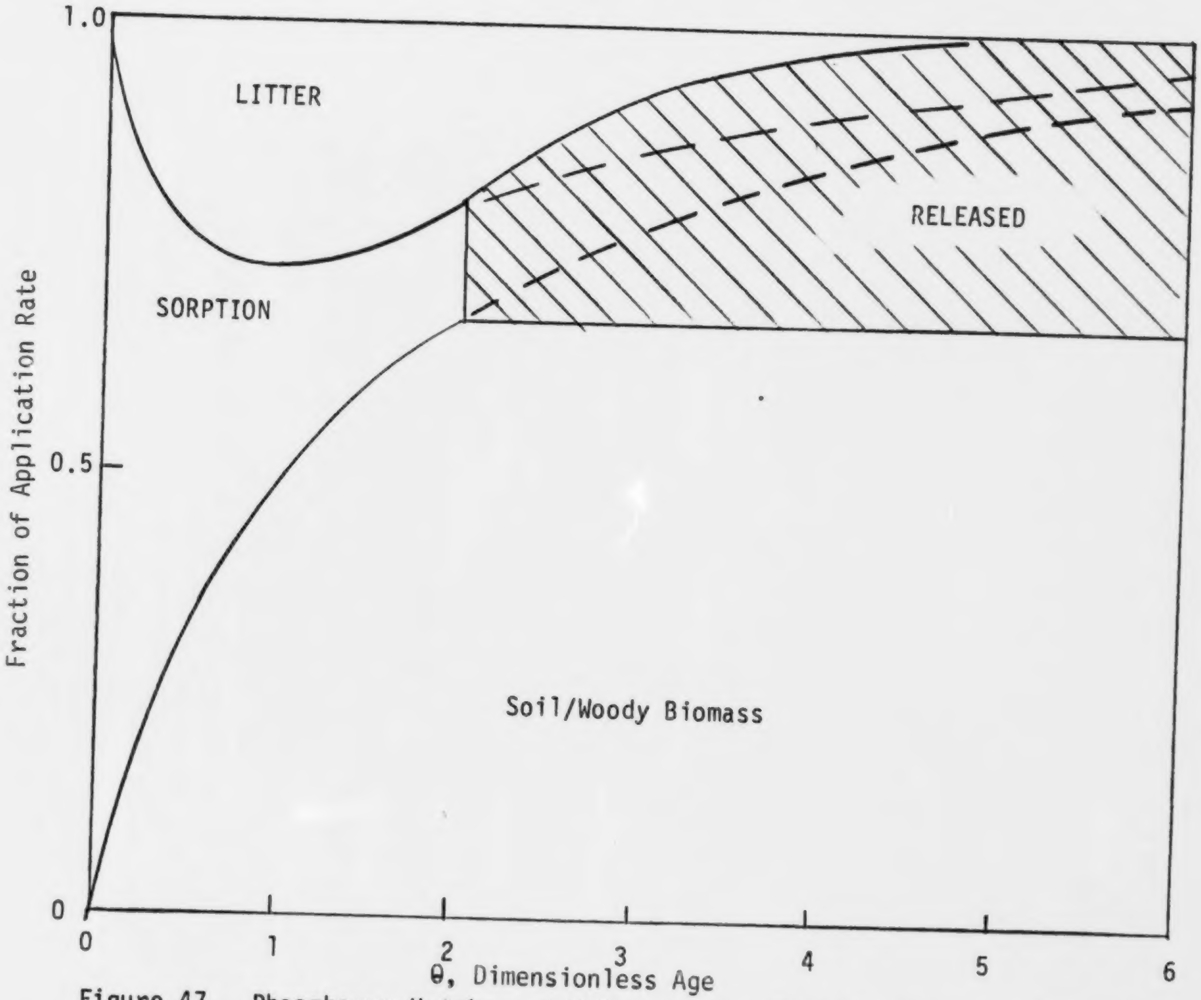


Figure 47. Phosphorus Uptake and Release for a Typical Wetland. Ultimate Capacity is Insufficient.
Basis: Wetland Area = 16.5 ha
Req'd Area = 25.0 ha
See Text for Other Data

Comparison of the Frontal Progression Model with Field Data

System parameters shown in Table 16 were estimated for the operation of the Houghton Lake treatment site. Utilizing the mass balance equation developed in the previous section (Equation 7.95) the predicted phosphorus front progression was calculated. The observed system behavior and the prediction are both plotted in Figure 48. Similar calculations were made for nitrogen front movement; the prediction and field data are shown in Figure 49.

The expansion of the "saturated" zones about the discharge point have been found to be much as predicted by the material balance, considering only the principle mechanisms discussed in Section 5. The aging of the Houghton Lake site can therefore be described by this model.

TABLE 16. PARAMETERS USED TO PREDICT PHOSPHORUS FRONT PROGRESSION AT THE HOUGHTON LAKE TREATMENT SITE

$QC_i = 342{,}000 \text{ gm/yr}$

$\alpha_d = 0.15 \text{ yr}^{-1}$

$R_p = 0.14 \frac{\text{gm}}{\text{m}^2 \text{ yr}}$

$x_L F = 0.69 \text{ gm/m}^2\text{/yr}$

$kZ_f C_\ell = 2.37 \text{ gm/m}^2$

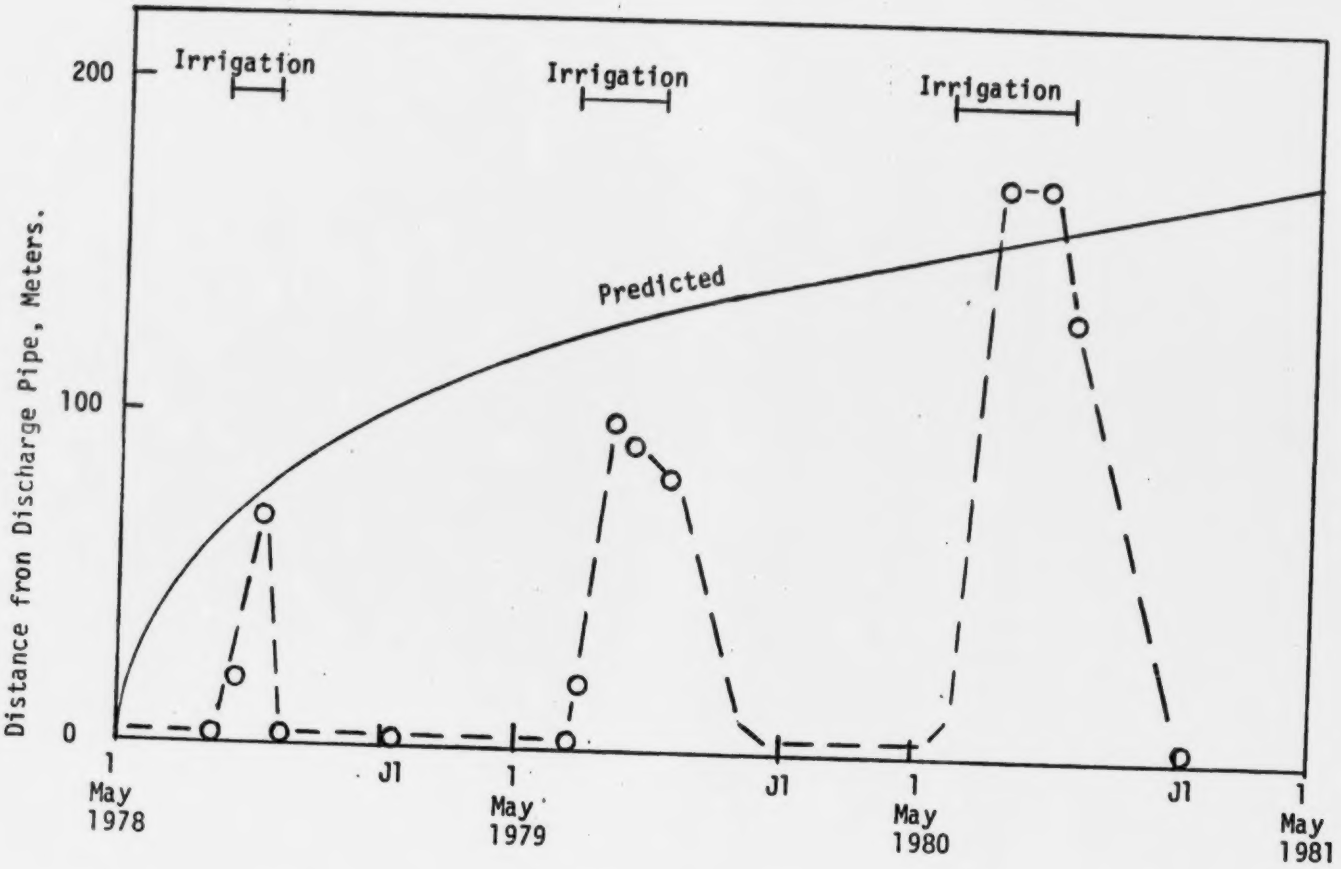


Figure 48. Movement of TDP Concentration Fronts in Surface Waters, C = 1 mg/l. Houghton Lake Treatment Site.

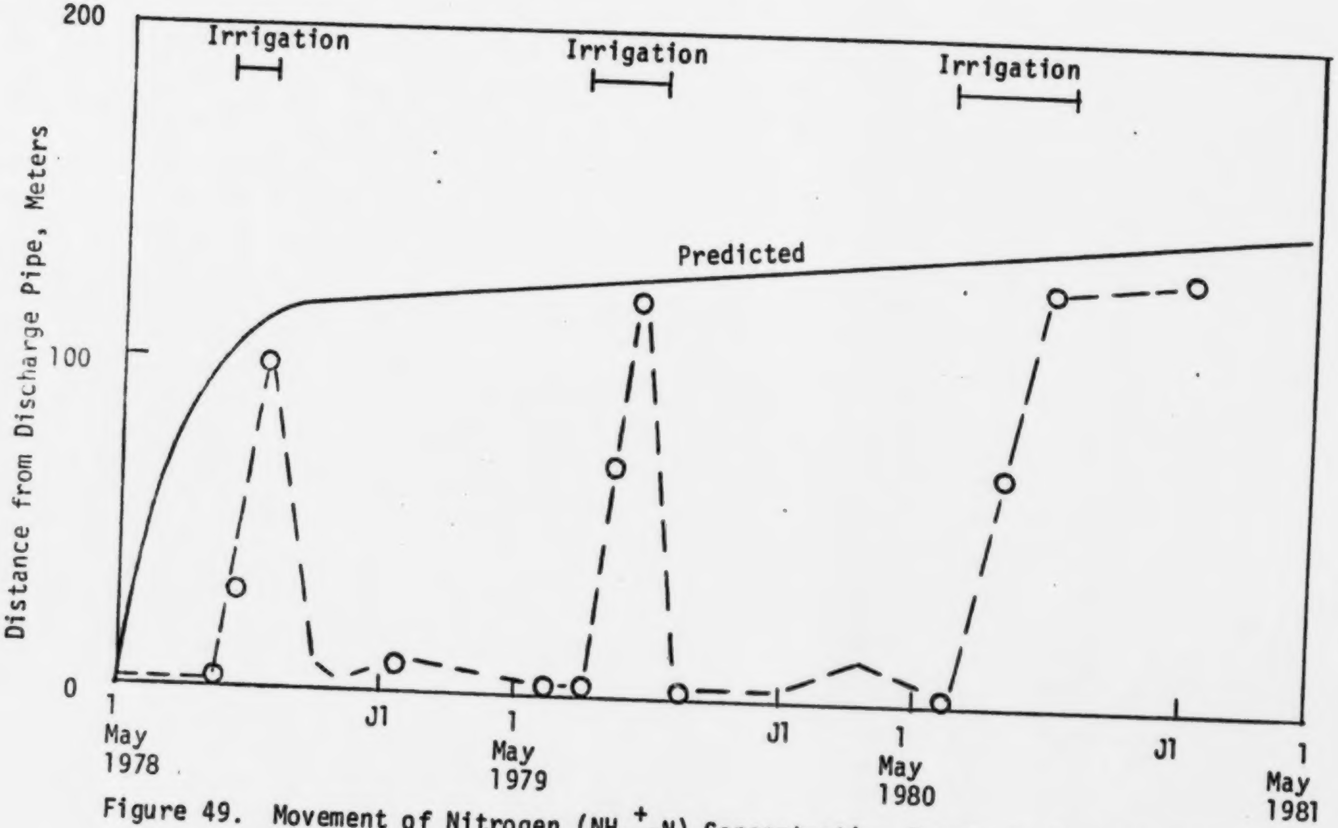


Figure 49. Movement of Nitrogen (NH_4^+-N) Concentration Fronts in Surface Waters, C=1 mg/l. Houghton Lake Treatment Site.

SECTION 8

WASTEWATER IMPACTS ON WETLANDS

By exposing a wetland to altered water levels or unusually high nutrient loads, changes within the ecosystem can be expected. Plant growth is generally accelerated and changes in the species composition can occur. As a result of alterations of the water depth and of the plant community, the make-up of the wetland fauna may also change. Wastewater may affect the soil substrate as well.

All of these changes within the wetland system must be evaluated with regard to the possible environmental costs or benefits. Such judgements are by nature subjective. Increased plant productivity and shifts in the species composition could be considered negative aspects of wetland treatment, simply because they constitute an alteration of the naturally evolving state of the ecosystem. Under these circumstances, any penalty incurred might best be considered in terms of the economic costs of alternate treatment methods or in terms of the ecological penalties incurred elsewhere if the wastewater were released without wetland treatment. No adequate system has been devised to quantify changes in the economic or ecological status of a wetland as the result of wastewater irrigation. However, decisions regarding wetland system designs must be based in part upon the available information on potential ecosystem changes.

No long-term studies have been completed to fully elucidate potential effects, but Table 17 contains a list of observed changes in wetlands that are believed to have been the result of AWT operations. Also included is a list of other potential ecosystem impacts which are at present only speculative. A comprehensive review of current knowledge on wastewater effects in wetlands has been prepared by WAPORA (1).

In some cases, researchers have considered wastewater irrigation to provide positive contributions to various wetland ecosystems. Improvements in wildlife habitats have been described for artificial wetlands such as Mt. View (30) and Vermontville (98). The availability of wastewater could constitute a valuable resource, for the creation of new wetland habitat or improvement of existing sites.

TABLE 17. WASTEWATER EFFECTS UPON WETLAND ECOSYSTEMS

OBSERVATIONS:

- Increased plant productivity
- Altered species composition within the plant community
- Altered animal populations as a result of food and habitat changes
- Altered soil/substrate
- Altered nutrient content and elemental analysis of plants

SPECULATIONS:

- Changes in detrital cycling
- Transfer of heavy metals and other toxins up the food chain
- Transmittal of viral or bacterial diseases at various levels of the food chain

SECTION 9

ECONOMICS

The economics of wetland treatment are attractive in those situations where there exists a suitable land parcel adjacent to the community. This appears to be true whether or not an existing wetland already exists at the site, although an existing wetland eliminates some construction costs.

Estimates of the economics of such systems have been presented by Sutherland (95) and Fritz and Helle (99). These are in excellent agreement on both capital and operating costs. Both deal with existing wetlands. Tables 18, 19, and 20 detail an example of cost estimation for a potential site. The basis for such an estimate must contain the following key items:

1. Total acreage to be obtained, for both irrigation and isolation.
2. Flows, both annual average and irrigation season actual.
3. Distance to the wetland from the treatment site.
4. Length of distribution pipe required within the wetland.
5. Pumping requirements, if any, expressed in terms of static, friction, and site discharge heads.
6. Disinfection requirements.
7. Harvesting requirements.
8. Grading, ditching, and diking requirements.
9. Plant community establishment.
10. Underdrain requirements.

The first seven items are common to all systems; the last three pertain only to constructed wetlands.

This type of analysis shows the major contributions to capital cost for an existing wetland to be pumps and piping, land and land access, and disinfection. Site alteration must be added for a constructed wetland. The major contributions to O & M costs are manpower, pumping energy, and monitoring costs.

TABLE 18. BASIS FOR EXAMPLE COST ESTIMATE FOR A WETLAND TREATMENT SYSTEM BASED ON THE NEEDS OF MAPLE RAPIDS, MI, FROM SUTHERLAND (95). EXISTING WETLAND.

Population served = 683

Av. daily flow (MGD) = 0.085

Actual flow (GPM) = 236

Force main length (ft) = 1,980

Force main size (in) = 4 and 6

Static head (ft) = -35

Friction loss (ft) = 10

Site pressure (ft) = 20

TDH to provide (ft) = 5

Gated pipe length (ft) = 2,400

Irrigated acreage = 44

Isolation acreage = -

Total acreage to be purchased - State owned = 0

Disinfection required

No harvesting

TABLE 19. CAPITAL COST ESTIMATE, MAPLE RAPIDS, MI, FROM SUTHERLAND (95).

Chlorination facilities	=	$ 25,000
Dechlorination pond	=	30,000
Pumping station	=	20,000
Forcemain* @ $ /ft.	=	19,720
Gated pipe and fixtures @ $21/ft.	=	50,400
Installation, initial	=	5,000
Crossings:		
Highway @$15,000	=	-
Interstate @ 50,000	=	-
Creek @ 5,000	=	-
River @ 30,000	=	-
Railroad @ 10,000	=	-
Access roadway** 3,900 ft. @ $14/ft.	=	54,600
Monitoring wells	=	2,000
Subtotal	=	$206,720
Construction cont. (10%)	=	20,672
Land State owned	=	0
Easement not needed	=	0
Total Capital Cost	=	$227,392

* 4-in. $8 x 428 ft.
6-in. $10.50 x 1,552 ft.

** in trees

TABLE 20. OPERATION AND MAINTENANCE COST ESTIMATE FOR MAPLE RAPIDS, MI, FROM SUTHERLAND (95).

O & M COSTS

Labor = $ 7,000

Power
9.0327 (GPM) (TDH) = 39

Chemicals
(2.45 GPM) = 578

Lab supplies, services = 2,000

Misc. repair,
replacement = 1,500

Administration = 2,000

Total O & M Costs = $13,117

Capital costs, estimated and actual, are shown in Figure 50. The estimates are those of Sutherland (95). The data are lower than these estimates for four cases; and higher for two cases. The reasons are instructive:

A) Houghton Lake, MI (high): added costs for 5700 feet of boat dock - pipe support, and a duplicate pump. Provisions for disinfection. No land cost, existing wetland.

B) Listowell, Ont. (high): constructed wetland; no land cost, elaborate flow control, harvest capability.

C) Humboldt, Sask. (low): constructed wetland; but no disinfection, no land cost.

D) Riverside, IA (low): gravity feed, no land, no disinfection, existing wetland.

E) Drummond, WI (low): gravity feed, no land, no disinfection, existing wetland.

F) Bellaire, MI (low): gravity feed, no land, no disinfection, existing wetland.

However, it is noted that for distances less than about 4-6 miles, the capital costs for existing wetland, no-harvest systems are attractive (95, 99).

Operation and Maintenance (O & M) costs are shown in Figure 51, with Sutherland's (95) estimates as a referent. Data are sparse, and difficult to determine accurately; but actual systems are cheap to run by any standard. They require little attention, essentially no chemicals, and have simple equipment. Actual data are confused by the current extraordinary monitoring requirements, which have been excluded from Figure 51. The Houghton Lake system currently requires an "extra" $10,000 per year for vegetation and animal research. Such expenditures are necessary to fill the gaps in our understanding of wetland systems - apparent throughout this report - but not essential to the performance of the system.

Capital recovery costs and O & M costs combine to yield a cost for advanced treatment for a gallon of wastewater. Figure 52 gives Fritz and Helle's (99) estimates for cypress strands for 200,000 gpd facilities. Sutherland's estimates for comparable size facilities are included, using a capital recovery factor of 0.1. Data for Houghton Lake and Bellaire are in reasonable agreement with their estimates. The estimates of Tchobanoglous and Culp (100) for total treatment costs are in agreement with the data and other estimates; in addition they support the economic advantage of artificial wetland systems for capacities up to 1.0 MGD.

Thus, from a cost viewpoint, wetland treatment looks attractive for small communities with appropriate land/wetland availability.

TABLE 21. SITE IDENTIFICATION KEY FOR FIGURES 50, 51, AND 52.

Estimates, (95):	
Au Gres, MI	○ AG
Deckerville, MI	○ D
Edmore, MI	○ E
Maple Rapids, MI	○ MR
Marcellus, MI	○ M
Ovekama, MI	○ O
Rosebush, MI	○ R
Scottville, MI	○ S
St. Charles, MI	○ SC
Westphalia, MI	○ W
Data:	
Houghton Lake, MI	● HL
Bellaire, MI	● B
Vermontville, MI	● V
Unnamed, MI	● SU
Drummond, WI	● D
Listowell, Ont.	● L
Humboldt, Sask.	● H
Riverside, IA	● R

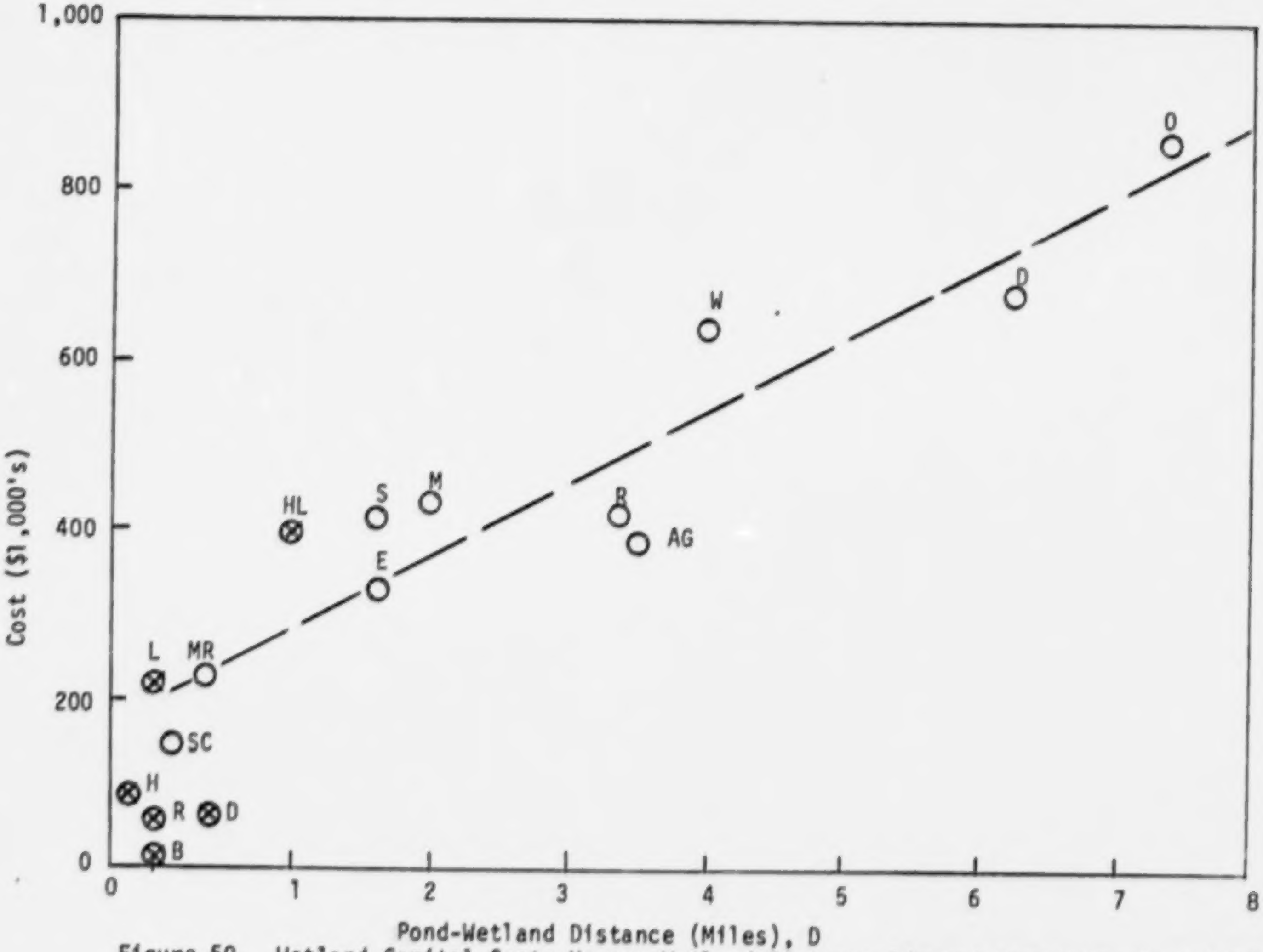


Figure 50. Wetland Capital Costs Versus Wetland Distance Adapted From Sutherland (95). See Table 21 for Site Symbol Identification.

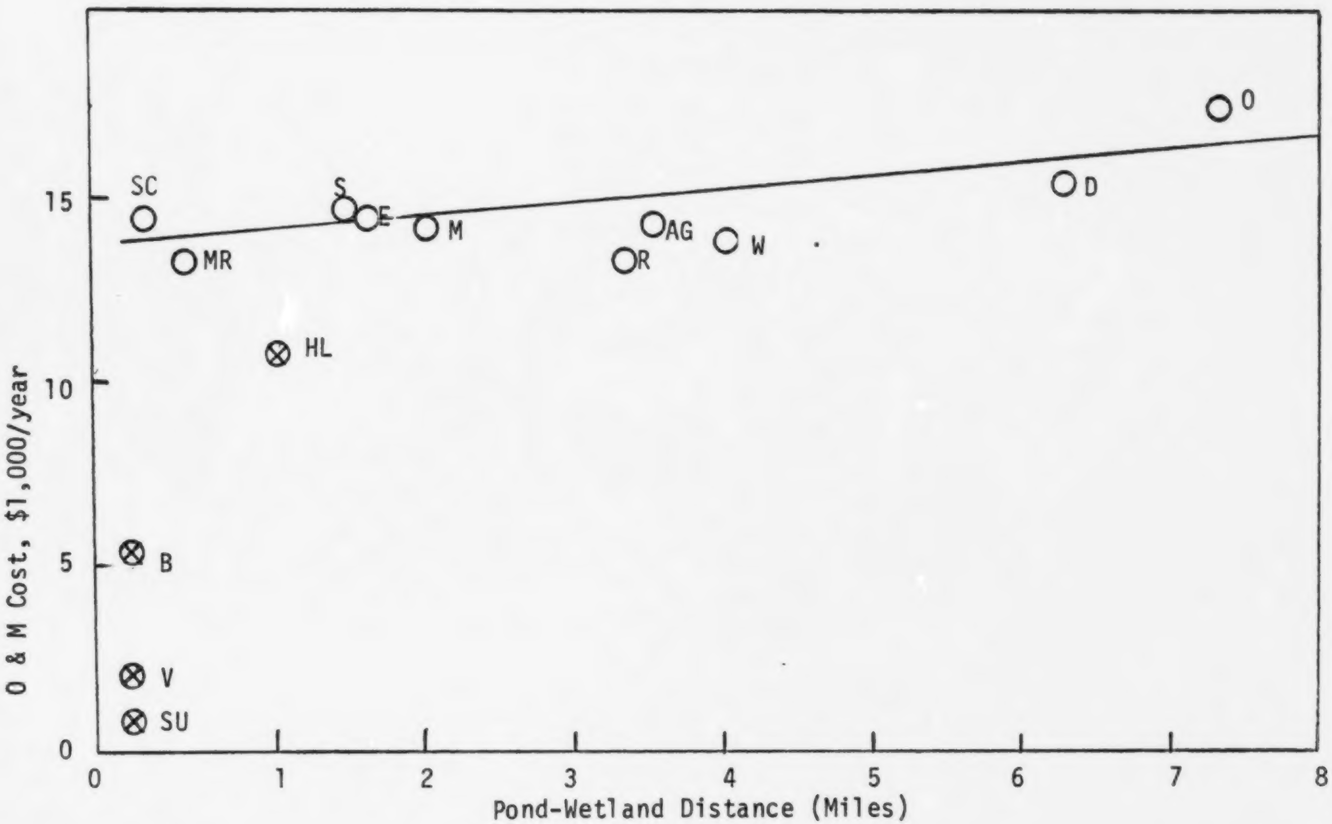


Figure 51. Wetland O & M Costs Versus Wetland Distance-Adapted from Sutherland(95). See Table 21 for Symbol Identification.

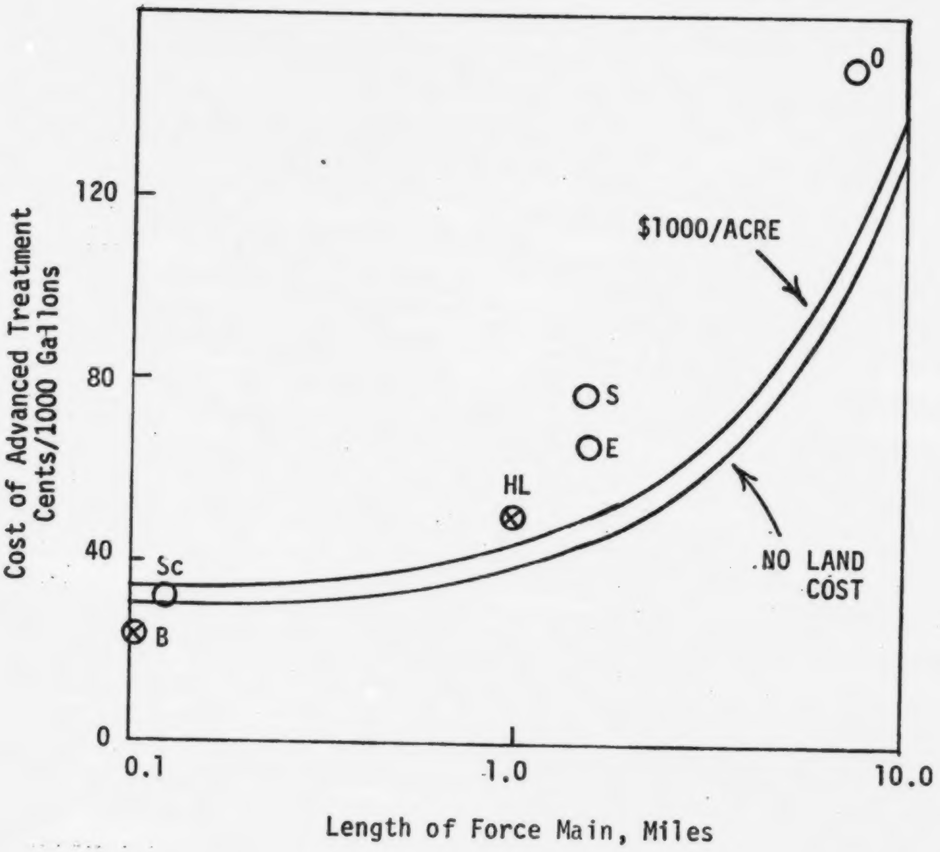


Figure 52. Incremental Cost Estimate for Wetland Treatment-Adapted From Fritz & Helle (1978). Curves Based on 0.2 Mgd. No Land Cost or $1000/Acre.
See Table 21 for Symbol Identification.

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APPENDIX

WETLAND TREATMENT SYSTEMS - DATA SOURCES

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BELLAIRE, Michigan

Stabilized wastewater has been discharged on a summer seasonal basis for a period of five years to this 40-acre partially forested wetland in the northern part of the lower peninsula of Michigan. Nutrient budgets are available, and the hydrology of the site has been studied to a moderate extent. Nutrient budgets are available at this site. Excellent removal of nitrogen and a diminishing removal of phosphorus are currently being displayed at this site. Research here is being conducted by a group of researchers from the University of Michigan.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Bellaire, Michigan

Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1972 to Present

Annual approximate discharge: 30×10^5 gal

Estimated affected area 30 acres

Wetland size 40 acres (area)

Distance from inlet to outlet 500 (approximate meters)

Type of water discharge:

____ Point discharge

____ Flood irrigation with gated pipe, ____ ft. in length

X Multiple point discharge at 3 locations

Typical monthly discharge schedule:

X Seasonally from May through October

____ Continuous discharge all year

____ Periodically, explain:

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

X none, relatively continuous discharge at predetermined rate for predetermined period

____ water depth in the wetland

____ water quality discharged to wetland

____ water quality at the wetland outflow

____ water quality at points inside the wetland

____ precipitation

____ other:

Wetland vegetation harvested: No

Description of harvesting technique: No

Disposal or use of harvested material: No

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X	X		
Total nitrogen content					
Dissolved nitrogen content	X	X	X		X
Total phosphorus content	X	X	X		

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X	X		X
Suspended solids (total)	X	X	X		
Volatile suspended solids	X	X	X		
Conductivity	X	X	X		X
pH	X	X	X		X
Chloride content	X	X	X		X
B.O.D.					
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________					
____________					
____________					

3. Hydrology

Data known to be available for one or more years:
Complete water budgets X
Water depth measurements ______
Soil elevations within the wetland (by survey with optical level or equivalent X
Estimates of subsurface water flow through the underlying soil ______
Estimates of the fraction channel flow as opposed to sheet flow ______
Details of water flow patterns across the wetland ______

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.
Total phosphorus ______
Total nitrogen ______
Suspended solids ______
Chloride ______
Heavy Metals ______
Other: ____________ ______
____________ ______
____________ ______

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants	X	
Vertebrates		
Invertebrates		
Algae	X	
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Kadlec, R. H., D. L. Tilton, "Monitoring Report on the Bellaire Wastewater Treatment Facility," Utilization Report No. 1, Univ. of Mich. Wetlands Ecosystem Research Group, (Two versions: Complete and Abridged), 1976-77.

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BRADFORD, Ontario

A long narrow natural marsh at Bradford, Ontario, has been monitored since 1979 in order to study processes such as evapotranspiration, nutrient assimilation, and other processes relating to nutrient, water and vegetation dynamics in natural wetlands.* This is a companion, small scale study, to that being conducted at Listowel, Ontario. Research reports from Bradford are not available at this point in time.

*Starting in the spring of 1981 sewage has been added and work is underway to attempt to describe how this will change the processes of the marsh.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Bradford, Ontario

Current as of September, 1981

1. Summary of System Management Technique

Dates of operation: 1979 to Present

Annual approximate discharge: 0.5×10^6 gal

Estimated affected area 900 m^2

Wetland size 900 m^2 (area)

Distance from inlet to outlet 180 (approximate meters)

Type of water discharge:

- X Point discharge
- ☐ Flood irrigation with gated pipe, ____ ft. in length
- ☐ Multiple point discharge at ____ locations

Typical monthly discharge schedule:

- ☐ Seasonally from ____ through ____
- X Continuous discharge all year
- ☐ Periodically, explain: ____

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

- X none, relatively continuous discharge at predetermined rate for predetermined period
- ☐ water depth in the wetland
- ☐ water quality discharged to wetland
- ☐ water quality at the wetland outflow
- ☐ water quality at points inside the wetland
- ☐ precipitation
- ☐ other: ____

Wetland vegetation harvested: No

Description of harvesting technique: ____

Disposal or use of harvested material: ____

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X			X
Total nitrogen content	X	X			X
Dissolved nitrogen content	X				
Total phosphorus content	X				

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X				X
Suspended solids (total)	X				
Volatile suspended solids	X				
Conductivity	X				
pH	X				
Chloride content	X				
B.O.D.	X				
C.O.D.	X				
Fecal coliform	X				
Fecal strep	X				
Viruses					
Heavy Metals	2/yr				
Organic chemicals/pesticides	2/yr				
Other: ________					
________					
________					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets X

Water depth measurements X

Soil elevations within the wetland (by survey with optical level or equivalent ________

Estimates of subsurface water flow through the underlying soil X

Estimates of the fraction channel flow as opposed to sheet flow ________

Details of water flow patterns across the wetland X

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X

Total nitrogen X

Suspended solids X

Chloride X

Heavy Metals ____

Other: ________ ____

________ ____

________ ____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		
Microorganisms		X
Viruses		
Sediments		X
Litter		X
Soil		X
Human use		
Land use		

6. Principal Data Sources

Slaughter, R., I. Wile, "Natural and Artificial Marshes for Sewage Treatment in Ontario," (Abstract), Presented at Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Wile, I., "An Experimental Approach to Wastewater Treatment Using Natural and Artificial Wetlands," Progress Report, Oct. 27, 1980.

BRILLION, Wisconsin

A research group from the University of Wisconsin-Oshkosh conducted this study over a two-year period in 1974 and 1975. The Brillion marsh is a large, deep water channelized fresh water marsh in south-central Wisconsin. Phosphorus removals and nitrogen removals were not as good as experienced at other research sites. The hydrology at Brillion is somewhat confused. Removals of nitrogen were approximately 50 percent and phosphorus removals were comparable. Some solids removal was also documented. This is a rather thorough study involving a large number of water quality parameters, as well as some estimates of the hydrology at the site.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Brillion, Wisconsin

Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1925 to Present

Annual approximate discharge: 98.3×10^6 gal

Estimated affected area 300 acres

Wetland size 385 acres (area)

Distance from inlet to outlet 1800 (approximate meters) (400 m channel included)

Type of water discharge:

X Point discharge

_____ Flood irrigation with gated pipe, _____ ft. in length

_____ Multiple point discharge at _____ locations

Typical monthly discharge schedule:

_____ Seasonally from _____ through _____

X Continuous discharge all year

_____ Periodically, explain: _____

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

X none, relatively continuous discharge at predetermined rate for predetermined period

_____ water depth in the wetland

_____ water quality discharged to wetland

_____ water quality at the wetland outflow

_____ water quality at points inside the wetland

_____ precipitation

_____ other: _____

Wetland vegetation harvested: No

Description of harvesting technique: _____

Disposal or use of harvested material: _____

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X		X		
Total nitrogen content					
Dissolved nitrogen content	X	X	X		
Total phosphorus content	X	X	X		

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content					
Suspended solids (total)	X	X	X		
Volatile suspended solids					
Conductivity	X	X	X		
pH	X	X	X		
Chloride content					
B.O.D.	X	X	X		
C.O.D.	X	X	X		
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ______					
______					
______					

3. Hydrology

Data known to be available for one or more years:
Complete water budgets ______
Water depth measurements ______
Soil elevations within the wetland (by survey with optical level or equivalent ______
Estimates of subsurface water flow through the underlying soil ______
Estimates of the fraction channel flow as opposed to sheet flow ______
Details of water flow patterns across the wetland ______

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X
Total nitrogen ______
Suspended solids ______
Chloride ______
Heavy Metals ______
Other: ______ ______
______ ______
______ ______

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Fetter, C. W., Jr., W. E. Sloey, F. L. Spangler, "Biogeochemical Studies of a Polluted Wisconsin Marsh," Presented at First Annual Wisconsin Water Resources Conference, Stevens Point, WI, pp. 13-49, Feb. 11, 1977.

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Spangler, F. L., W. E. Sloey, C. W. Fetter, Jr., "Wastewater Treatment by Natural and Artificial Marshes," Prepared for: Robert S. Kerr Environmental Research Lab, Ada, OK, NTIS Report, PB-259 992, EPA 600/2-76-207, Sept. 1976.

BROOKHAVEN, Long Island, New York

A series of tests were performed at the Brookhaven National Laboratory on the ability of an artificially constructed marsh/meadow/pond system. Various configurations were tested. The influent to this system was raw sewage blended with septage and sludge. Studies span the period 1975 through 1977. A wide variety of water quality parameters were studied. No problems in establishing a cattail community were found. Excellent water rennovation was accomplished, with lesser results during the winter season for some of the parameters.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Brookhaven, N.Y. (Artificial)
Current as of July, 1979

1. Summary of System Management Technique
   Dates of operation: Spring,73 to Jan,79
   Annual approximate discharge: ~3 mm gal
   Estimated affected area 0.4 acres
   Wetland size 0.4 acres (area)
   Distance from inlet to outlet 100 (approximate meters)
   Type of water discharge:
   X Point discharge
   ___ Flood irrigation with gated pipe, ___ ft. in length
   ___ Multiple point discharge at ___ locations
   Typical monthly discharge schedule:
   ___ Seasonally from ___ through ___
   X Continuous discharge all year
   ___ Periodically, explain: ___

   Factors which have actually been used to make decisions to modify the wastewater discharge rate:
   X none, relatively continuous discharge at predetermined rate for predetermined period
   ___ water depth in the wetland
   ___ water quality discharged to wetland
   ___ water quality at the wetland outflow
   ___ water quality at points inside the wetland
   ___ precipitation
   ___ other: ___

   Wetland vegetation harvested: Yes

   Description of harvesting technique: Wheeled tractor with rotary cutter and manual collection.
   Disposal or use of harvested material: ___

2. Overall Budgets for Water-borne Components
   Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X			
Total nitrogen content	X	X			
Dissolved nitrogen content	X	X			
Total phosphorus content	X	X			

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X			
Suspended solids (total)	X	X			
Volatile suspended solids	X	X			
Conductivity	X	X			
pH	X	X			
Chloride content	X	X			
B.O.D.	X	X			
C.O.D.	X	X			
Fecal coliform	X	X			
Fecal strep					
Viruses					
Heavy Metals	X	X			
Organic chemicals/pesticides					
Other: ________					
________					
________					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets ________

Water depth measurements ___X___

Soil elevations within the wetland (by survey with optical level or equivalent ________

Estimates of subsurface water flow through the underlying soil ________

Estimates of the fraction channel flow as opposed to sheet flow ________

Details of water flow patterns across the wetland ________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus ____

Total nitrogen ____

Suspended solids ____

Chloride ____

Heavy Metals ____

Other: ________ ____

________ ____

________ ____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments	X	
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Small, M. M., "Marsh/Pond Systems as Sewage Treatment Plants," Brookhaven National Laboratory, Upton, NY, 39 p., 1975.

Small, M. M., "Marsh/Pond System," Brookhaven National Laboratory, Upton, NY, 28 p., 1976.

Small, M. M., "Marsh/Pond Sewage Treatment Plants," Presented at the Conference on Freshwater Wetlands and Sewage Effluent Disposal, Univ. of Mich., May 10-11, 1976.

Small, M. M., "Artificial Wetlands as Non-Point Source Wastewater Treatment Systems," Proceedings: Environmental Quality Through Wetlands Utilization, Tallahassee, FL, pp. 171-181, Feb. 28-March 2, 1978.

Small, M. M., "Wetlands Wastewater Treatment Systems," Presented at the International Symposium, State of Knowledge in Land Treatment of Wastewater, Hanover, New Hampshire, August 20-25, 1978.

Small, M. M., "Meadow/Marsh/Pond System," Brookhaven National Laboratory, Upton, NY, 33 p., 1977.

Small, M. M., "Marsh/Pond Sewage Treatment Plants II," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

CLERMONT, Florida

In a study spaning at least two years, a group from the Florida Center for Wetlands at Gainesville, studied the ability of a fresh water marsh in central Florida to assimilate nitrogen and phosphorus. The studies at this site were conducted on relatively small test cells, with measurements being made of water, soil and vegetative compartments. Principle emphasis of this project appears to have been to establish nutrient budgets at this particular site. A very detailed report on nitrogen and phosphorus cycling and assimilation at this research site has been issued. Results show nutrient assimilation to be remarkably effective.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Clermont, Florida
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1977 to 1979
Annual approximate discharge: 4 x 10^6 gal
Estimated affected area 6000 m^2
Wetland size 32 ha (area)
Distance from inlet to outlet ______ (approximate meters)
Type of water discharge:
____ Point discharge
X Flood irrigation with gated pipe, 98 ft. in length
____ Multiple point discharge at ____ locations
Typical monthly discharge schedule:
____ Seasonally from ______ through ______
____ Continuous discharge all year
X Periodically, explain: water applied over a 24 hour period once each week

Factors which have actually been used to make decisions to modify the wastewater discharge rate:
X none, relatively continuous discharge at predetermined rate for predetermined period
____ water depth in the wetland
____ water quality discharged to wetland
____ water quality at the wetland outflow
____ water quality at points inside the wetland
____ precipitation
____ other:

Wetland vegetation harvested: No

Description of harvesting technique:

Disposal or use of harvested material:

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X	X	X	
Total nitrogen content	X	X	X	X	
Dissolved nitrogen content	X	X	X	X	
Total phosphorus content	X	X	X	X	

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content					
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content	X	X	X	X	
B.O.D.					
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________					
____________					
____________					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets X

Water depth measurements X

Soil elevations within the wetland (by survey with optical level or equivalent X

Estimates of subsurface water flow through the underlying soil X

Estimates of the fraction channel flow as opposed to sheet flow ______

Details of water flow patterns across the wetland ______

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X

Total nitrogen X

Suspended solids ____

Chloride ____

Heavy Metals ____

Other: ________ ____

________ ____

________ ____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		X
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		X
Human use		
Land use		

6. Principal Data Sources

Dolan, T. J., S. E. Bayley, J. Zoltek, Jr., A. Hermann, "The Clermont Project: Renovation of Treated Effluent by a Freshwater Marsh: Biomass Production and Phosphorus Results," Proceedings: Environmental Quality Through Wetlands Utilization, Tallahassee, FL, pp. 132-152, March 2, 1978.

Hermann, A., J. Zoltek, Jr., S. E. Bayley, T. Dolan, "Nutrient Budget in a Fluctuating Freshwater Marsh System in Florida," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Zoltek, J., Jr., S. E. Bayley, et al., "Removal of Nutrients from Treated Municipal Wastewater by Freshwater Marshes," Final Report to City of Clermont, Florida Center for Wetlands, University of Florida, October 1979.

Dolan, T. J., S. E. Bayley, J. Zoltek, Jr., A. Hermann, "The Clermont Project: Renovation of Treated Effluent by a Freshwater Marsh," In: Environmental Quality Through Wetlands Utilization, Coord. Council on the Restoration of the Kissimmee River Valley, March 1978, M. A. Drew, Ed., pp. 132-152.

COOTES PARADISE, Ontario

Cootes Paradise is a 5.2 km^2 wildlife sanctuary near Hamilton, Ontario. The Dundas sewage treatment plant began discharging to the wetland in 1919. The wetland is channelized. Heavy metals have accumulated; species composition changes have occurred. Sediments are important sinks.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Cootes Paradise, Ontario
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1920 to Present
Annual approximate discharge: _____ gal
Estimated affected area 1.7 km
Wetland size 5.2 km^2 (area)
Distance from inlet to outlet _____ (approximate meters)
Type of water discharge:
X Point discharge
_____ Flood irrigation with gated pipe, _____ ft. in length
_____ Multiple point discharge at _____ locations
Typical monthly discharge schedule:
_____ Seasonally from _____ through _____
X Continuous discharge all year
_____ Periodically, explain: _____

Factors which have actually been used to make decisions to modify the wastewater discharge rate:
X none, relatively continuous discharge at predetermined rate for predetermined period
_____ water depth in the wetland
_____ water quality discharged to wetland
_____ water quality at the wetland outflow
_____ water quality at points inside the wetland
_____ precipitation
_____ other: _____

Wetland vegetation harvested: No

Description of harvesting technique: _____

Disposal or use of harvested material: _____

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X			
Total nitrogen content	X	X	X		
Dissolved nitrogen content	X	X	X		
Total phosphorus content	X	X	X		

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content					
Suspended solids (total)	X	X	X		
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.					
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals	X	X	X		
Organic chemicals/pesticides					
Other: ______					
______					
______					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets ______

Water depth measurements X

Soil elevations within the wetland (by survey with optical level or equivalent ______

Estimates of subsurface water flow through the underlying soil ______

Estimates of the fraction channel flow as opposed to sheet flow ______

Details of water flow patterns across the wetland ______

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X

Total nitrogen X

Suspended solids ______

Chloride ______

Heavy Metals X

Other: ______ ______

______ ______

______ ______

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		X
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		X
Litter		
Soil		X
Human use		
Land use		

6. Principal Data Sources

Mudroch, A., J. A. Capobianco, "Effects of Treated Effluent on a Natural Marsh," Journal WPCF, Vol. 51, No. 9, Sept. 1979, pp. 2243-56.

DRUMMOND, Wisconsin

The Drummond project started in 1979. This sphagnum-spruce bog in northern Wisconsin receives treated wastewater from stabilization ponds near the small town of Drummond. Rather extensive study of the hydrology, water quality, and biological compartments is currently under way. A large variety of agencies have been involved, and no centralized report is yet available.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Drummond, Wisconsin
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1979 to Present
Annual approximate discharge: 15×10^6 gal
Estimated affected area 20 acres
Wetland size 27 acres (area)
Distance from inlet to outlet 200 (approximate meters)
Type of water discharge:

- ___ Point discharge
- X Flood irrigation with gated pipe, 400 ft. in length
- ___ Multiple point discharge at ___ locations

Typical monthly discharge schedule:

- X Seasonally from May through October
- ___ Continuous discharge all year
- ___ Periodically, explain: ___

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

- ___ none, relatively continuous discharge at predetermined rate for predetermined period
- ___ water depth in the wetland
- ___ water quality discharged to wetland
- ___ water quality at the wetland outflow
- ___ water quality at points inside the wetland
- X precipitation
- ___ other: ___

Wetland vegetation harvested: No

Description of harvesting technique: ___

Disposal or use of harvested material: ___

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X		X	X
Total nitrogen content	X	X		X	X
Dissolved nitrogen content					
Total phosphorus content	X	X		X	X

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content					
Suspended solids (total)					
Volatile suspended solids	X	X		X	X
Conductivity					
pH	X	X		X	X
Chloride content	X	X		X	X
B.O.D.	X	X			X
C.O.D.	X	X			
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ______					
______					
______					

3. Hydrology

Data known to be available for one or more years:
Complete water budgets __X__
Water depth measurements __X__
Soil elevations within the wetland (by survey with optical level or equivalent ______
Estimates of subsurface water flow through the underlying soil __X__
Estimates of the fraction channel flow as opposed to sheet flow __X__
Details of water flow patterns across the wetland __X__

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.
Total phosphorus __X__
Total nitrogen __X__
Suspended solids ____
Chloride __X__
Heavy Metals __X__
Other: ______ ____
______ ____
______ ____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		X
Soil		X
Human use		
Land use		

6. Principal Data Sources

Kappel, W., "The Drummond Project," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Kappel, W. M., U.S. Geological Survey, "The Drummond Project - Applying Lagoon Sewage Effluent to a Bog; An Operational Trial," In: Seminar Proceedings on Aquaculture Systems for Wastewater Treatment, Univ. of California at Davis, USEPA 430/9-80-006, Sept. 1979, Pub. No. MCD-67, Bastian and Reed, Ed.

Anderson, R. K., and D. Kent, Progress Report: Drummond Wisconsin, Tertiary Treatment Demonstration Project Study. Report to the U.S. Fish and Wildlife Service. University of Wisconsin, Stevens Point, WI, 22 p., 1979.

Guntenspergen, G., and F. Stearns, "Ecology of an Ombrotrophic Bog," Summary of a presentation to the Ecological Society of America, Stillwater, OK, 9 p., 1979.

Guntenspergen, G., W. Kappel, F. Stearns, "Response of a Bog to Application of Lagoon Sewage: The Drummond Project - An Operational Trial," Summary Project Report, Sept. 10, 1980.

Anonymous, "Nature's Filter," Audubon, July 1980, p. 140.

Mechenich, D. J., "Tertiary Wastewater Treatment Using a Natural Peat Bog," Masters thesis, College of Natural Resources, University of Wisconsin, Stevens Point, WI, 1980, 136 p.

Reim, J., "Sewage Treatment in a Sphagnum Peat Bog," Great Lakes Focus on Water Quality, 6(3):6-9, 1980.

Wikum, D., and M. Ondrus, "The Drummond Bog Project: Growth of Selected Plant Species as a Function of Foliar and Peat Substrate Nutrient Concentrations," Report to the U.S. Forest Service, University of Wisconsin, Stout, WI, 1980, 38 p.

DULAC, Louisiana

This study was conducted with the introduction of fish processing waste to a fresh water marsh in Louisiana. Small scale test areas were subjected to sprayings of liquid fish plant waste. Nitrogen and phosphorus, as well as biomass data, were collected during the summer season of 1973. Approximately half of the carbon nitrogen and phosphorus were removed from the wastewater in a relatively short retention time at the edge of the marsh. Biomass increases were significant but could not be statistically defended.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Dulac, Louisiana

Current as of July, 1976

1. Summary of System Management Technique

Dates of operation: 1973 to 1974

Annual approximate discharge: 33,150 gal

Estimated affected area 0.03 ha

Wetland size 170 ha (area)

Distance from inlet to outlet 10 (approximate meters)

Type of water discharge:

____ Point discharge
____ Flood irrigation with gated pipe, ____ ft. in length
X Multiple point discharge at 12 locations

Typical monthly discharge schedule:

____ Seasonally from ____ through ____
____ Continuous discharge all year
X Periodically, explain: biweekly

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

X none, relatively continuous discharge at predetermined rate for predetermined period
____ water depth in the wetland
____ water quality discharged to wetland
____ water quality at the wetland outflow
____ water quality at points inside the wetland
____ precipitation
____ other:

Wetland vegetation harvested: No

Description of harvesting technique:

Disposal or use of harvested material:

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X			X
Total nitrogen content	X	X			X
Dissolved nitrogen content	X	X			X
Total phosphorus content	X	X			X

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X			X
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.					
C.O.D.					
Fecal coliform	X	X		X	X
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: carbon	X	X			X

3. Hydrology

Data known to be available for one or more years:

Complete water budgets ____

Water depth measurements ____

Soil elevations within the wetland (by survey with optical level or equivalent X

Estimates of subsurface water flow through the underlying soil ____

Estimates of the fraction channel flow as opposed to sheet flow ____

Details of water flow patterns across the wetland ____

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X

Total nitrogen X

Suspended solids ____

Chloride ____

Heavy Metals ____

Other: carbon X

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		
Microorganisms		X
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Smith, W. G., and J. W. Day, "Enrichment of Marsh Habitats with Organic Wastes," Louisiana Water Resources Research Institute, Baton Rouge, LA, 9 p., 1973.

Meo, M., J. W. Day, Jr., T. B. Ford, "Land Treatment of Fish Processing Wastes on Dredge Spoin Sites: Comparative Cost Evaluations," Coastal Zone Management Journal, 3, 3, pp. 307-318, 1977.

Turner, R. E., J. W. Day, Jr., M. Meo, P. M. Payonk, T. B. Ford, W. G. Smith, "Aspects of Land-Treated Waste Applications in Louisiana Wetlands," Presented at the Conference on Freshwater Wetlands and Sewage Effluent Disposal, Univ. of Mich., Ann Arbor, MI, May 10-11, 1976.

GAINESVILLE, Florida

Wastewater from a package plant at a trailer park has been pumped to small cypress domes in this central Florida location for a number of years. A very extensive research project under the auspices of the Center for Wetlands at the University of Florida has accompanied this effort. All components of the ecosystem, including the soils, water and other abiotic components, have been studied in great detail. Excellent water renovation has been displayed at this site. Percolation is downward to groundwater during most periods of the year, although overflow to surrounding ecosystems is possible at times. This study includes some virology and bacteriology as well as heavy metals work. A complete set of documentation is available in the form of five annual reports. A book summarizing the results is forthcoming.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Gainesville, Florida

Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1973 to Present

Annual approximate discharge: 6×10^6 gal

Estimated affected area 1.5 ha

Wetland size 1.5 ha (area)

Distance from inlet to outlet 50 (approximate meters)

Type of water discharge:

X Point discharge

____ Flood irrigation with gated pipe, ____ ft. in length

____ Multiple point discharge at ____ locations

Typical monthly discharge schedule:

____ Seasonally from ____ through ____

X Continuous discharge all year

____ Periodically, explain: ____

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

X none, relatively continuous discharge at predetermined rate for predetermined period

____ water depth in the wetland

____ water quality discharged to wetland

____ water quality at the wetland outflow

____ water quality at points inside the wetland

____ precipitation

____ other: ____

Wetland vegetation harvested: No

Description of harvesting technique: ____

Disposal or use of harvested material: ____

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X		X	X
Total nitrogen content	X	X		X	X
Dissolved nitrogen content	X	X		X	X
Total phosphorus content	X	X		X	X

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X		X	X
Suspended solids (total)	X	X		X	X
Volatile suspended solids					
Conductivity	X	X		X	X
pH	X	X		X	X
Chloride content	X	X		X	X
B.O.D.	X	X		X	X
C.O.D.					
Fecal coliform	X	X		X	X
Fecal strep					
Viruses	X	X		X	X
Heavy Metals	X	X		X	X
Organic chemicals/pesticides					
Other: sulfur	X	X		X	X

3. Hydrology

Data known to be available for one or more years:

Complete water budgets X

Water depth measurements X

Soil elevations within the wetland (by survey with optical level or equivalent X

Estimates of subsurface water flow through the underlying soil X

Estimates of the fraction channel flow as opposed to sheet flow ______

Details of water flow patterns across the wetland X

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X

Total nitrogen X

Suspended solids X

Chloride X

Heavy Metals X

Other: ______ ______

______ ______

______ ______

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		X
Invertebrates		X
Algae		
Microorganisms		X
Viruses		X
Sediments		X
Litter		X
Soil		X
Human use		X
Land use		X

6. Principal Data Sources

Ewel, K. C., "Effects of Sewage Effluent on Ecosystem Dynamics in Cypress Domes," Presented at the Conference on Freshwater Wetlands and Sewage Effluent Disposal, Univ. of Mich., Ann Arbor, MI, May 10-11, 1976.

Ewel, K. C., "Effects of Sewage Recycling on Structure and Function of Cypress Ecosystems," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Fritz, W. R., and S. C. Helle, Cypress Wetlands for Tertiary Treatment, Boyle Engineering Corporation, Orlando, FL, Report to NSF, Grant #ENV76-23276, 1979.

Odum, H. T., K. C. Ewel, J. W. Ordway, M. K. Johnston, W. J. Mitsch, "Cypress Wetlands for Water Management Recycling and Conservation," Annual Project Report to NSF, Grant #GI-28721 and to the Rockefeller Foundation, Grant #RF-73029, 1974.

Fritz, W. R. and S. C. Helle, "Updated Preliminary Report - Tertiary Treatment of Wastewater Using Cypress Wetlands," Report to NSF, Grant #ENV76-23276, Nov. 1977.

Wellings, F. M., "Viral Aspects of Wetland Disposal of Effluent," Proceedings of the Symposium on Freshwater Wetlands and Sewage Effluent Disposal, Univ. of Mich., Ann Arbor, MI, pp. 297-305, May 10-11, 1976.

Odum, H. T., K. C. Ewel, J. W. Ordway, M. K. Johnston, "Cypress Wetlands for Water Management, Recycling and Conservation," Second Annual Report to NSF, Grant #AEN-07823A01, and the Rockefeller Foundation, Grant # RF-73029, Dec. 1975.

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GREAT MEADOWS, Massachusetts

This study, conducted by IEP of Wayland, Massachusetts, details a two-year study of a wetland near the Concord River in Lexington, Massachusetts. This wetland was basically a deep water, fresh water marsh that had been receiving effluent for some sixty-eight years prior to the study. The principal water quality parameters still showed significant reductions: phosphorus at approximately 60 percent and nitrogen at above 90 percent. Suspended solids were shown to be reduced at this site as well. This is a very detailed study done by a professional consulting organization. The discharge to the wetland was to be discontinued in 1979, due to its classification as a wildlife refuge. This report does some speculation based on the literature concerning discharge of secondary wastewater to wetlands.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Great Meadows, Massachusetts

Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1912(?) to 1980

Annual approximate discharge: 1.6×10^9 gal

Estimated affected area 54 acres

Wetland size 54 acres (area)

Distance from inlet to outlet 700 (approximate meters)

Type of water discharge:

X Point discharge

___ Flood irrigation with gated pipe, ___ ft. in length

___ Multiple point discharge at ___ locations

Typical monthly discharge schedule:

___ Seasonally from ___ through ___

X Continuous discharge all year

___ Periodically, explain: ___

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

X none, relatively continuous discharge at predetermined rate for predetermined period

___ water depth in the wetland

___ water quality discharged to wetland

___ water quality at the wetland outflow

___ water quality at points inside the wetland

___ precipitation

___ other: ___

Wetland vegetation harvested: No

Description of harvesting technique: ___

Disposal or use of harvested material: ___

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X		X		
Total nitrogen content	X	X			X
Dissolved nitrogen content	X	X			X
Total phosphorus content	X	X			X

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X			X
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content	X	X			X
B.O.D.	X	X			X
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________					
____________					
____________					

3. Hydrology

Data known to be available for one or more years:
Complete water budgets ________
Water depth measurements ________
Soil elevations within the wetland (by survey with optical level or equivalent ________
Estimates of subsurface water flow through the underlying soil ________
Estimates of the fraction channel flow as opposed to sheet flow ________
Details of water flow patterns across the wetland ________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus ____
Total nitrogen ____
Suspended solids ____
Chloride ____
Heavy Metals ____
Other: ________ ____
________ ____
________ ____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants	X	
Vertebrates		
Invertebrates		X
Algae		
Microorganisms		
Viruses		
Sediments	X	
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

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HAMILTON, New Jersey

Research was conducted at the Hamilton Township Sewage Treatment plant in Trenton, New Jersey. Wastewater from the sewage treatment plant was used to irrigate relatively small (10m x 20m) enclosures in a variety of different ways. Different loadings and different nutrient contents were tried at different time periods during the tide cycle. Monthly water samples were collected and analyzed for nitrogen, phosphorus, carbon dioxide, oxygen, and alkalinity. Decomposition rates were determined, and some species composition data acquired. The Hamilton wetland is a fresh water tidal wetland. I believe there is no long term data from this site, because I believe their research discontinued after approximately three years. This is a relatively detailed study done by university people, and consequently suffers only from the short time period over which the study was conducted.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Hamilton Marshes, New Jersey
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1975 to 1977
Annual approximate discharge: 1.7 x 10^6 gal
Estimated affected area 200 m^2 each
Wetland size 500 ha (area)
Distance from inlet to outlet 10 (approximate meters)
Type of water discharge:

- ___ Point discharge
- ___ Flood irrigation with gated pipe, ___ ft. in length
- X Multiple point discharge at ___ locations

Typical monthly discharge schedule:

- X Seasonally from April through December
- ___ Continuous discharge all year
- ___ Periodically, explain:

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

- X none, relatively continuous discharge at predetermined rate for predetermined period
- ___ water depth in the wetland
- ___ water quality discharged to wetland
- ___ water quality at the wetland outflow
- ___ water quality at points inside the wetland
- ___ precipitation
- ___ other:

Wetland vegetation harvested: No (except for biomass and nutrient studies)
Description of harvesting technique:
Disposal or use of harvested material:

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X				
Total nitrogen content					
Dissolved nitrogen content	X		X		X
Total phosphorus content					

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X		X		X
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.					
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________					
____________					
____________					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets ________

Water depth measurements ________

Soil elevations within the wetland (by survey with optical level or equivalent ________

Estimates of subsurface water flow through the underlying soil ________

Estimates of the fraction channel flow as opposed to sheet flow ________

Details of water flow patterns across the wetland ________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X }for several summer tidal cycles
Total nitrogen X
Suspended solids ____
Chloride ____
Heavy Metals ____
Other: ________ ____
________ ____
________ ____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		X
Microorganisms		
Viruses		
Sediments		
Litter		X
Soil		X
Human use		
Land use		

6. Principal Data Sources

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HAY RIVER, Northwest Territories

Sewage effluent from the town of Hay River, Northwest Territories, Canada, is released into a seasonal stream, and flows about 6 km from the discharge site into Great Slave Lake. Throughout much of the year, the stream comprises of a series of channels, ponds and swamps, with little flow. The majority of the sewage is discharged from stabilization lagoons, with about 20% of the total released directly, untreated. Substantial improvement in water quality is achieved. Elevated standing crops of Typha and Carex are reported. Discharge began in 1970.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Hay River, Northwest Territories
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1965(?) to Present
Annual approximate discharge: 11×10^6 gal
Estimated affected area 32 ha
Wetland size 47 ha (area)
Distance from inlet to outlet 5,860 (approximate meters)

Type of water discharge:
X Point discharge
_____ Flood irrigation with gated pipe, _____ ft. in length
_____ Multiple point discharge at _____ locations

Typical monthly discharge schedule:
_____ Seasonally from __________ through __________
X Continuous discharge all year
_____ Periodically, explain: __________

Factors which have actually been used to make decisions to modify the wastewater discharge rate:
X none, relatively continuous discharge at predetermined rate for predetermined period
_____ water depth in the wetland
_____ water quality discharged to wetland
_____ water quality at the wetland outflow
_____ water quality at points inside the wetland
_____ precipitation
_____ other: __________

Wetland vegetation harvested: Sedge

Description of harvesting technique: __________

Disposal or use of harvested material: __________

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate					
Total nitrogen content					
Dissolved nitrogen content	X	X			X
Total phosphorus content	X	X			X

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X			X
Suspended solids (total)	X	X			X
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.	X	X			X
C.O.D.					
Fecal coliform	X	X			
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: Sulfate	X	X			
Surfactants	X	X			

3. Hydrology

Data known to be available for one or more years:

Complete water budgets __________

Water depth measurements __________

Soil elevations within the wetland (by survey with optical level or equivalent __________

Estimates of subsurface water flow through the underlying soil ________

Estimates of the fraction channel flow as opposed to sheet flow _______

Details of water flow patterns across the wetland __________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X

Total nitrogen _____

Suspended solids _____

Chloride _____

Heavy Metals _____

Other: __________ _____

__________ _____

__________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		X
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Hartland-Rowe, R., and P. B. Wright, "Effects of Sewage Effluent on a Swampland Stream," Verh. Int. Ver. Limnol, Vol. 19, p. 1575, 1975.

HOUGHTON LAKE, Michigan

Research at this site has been under way since 1971, and includes several different scales of additions of secondary wastewater to a sedge-leatherleaf area in central Michigan. Water renovation has been excellent at all scales of operation, and a large amount of data has been acquired concerning all aspects of that waste treatment operation. Studies include some work on viruses, vertebrates, invertebrates, and extensive work on the vegetation of the area. Water quality, sediments and soils have been studied extensively. The current full-scale operation, averaging 1,000,000 gallons of water per day during the summer season, has been under way for three years at this location.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Houghton Lake, Michigan
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1975 to Present
Annual approximate discharge: 100×10^6 gal
Estimated affected area 100 Acres
Wetland size 1700 Acres (area)
Distance from inlet to outlet 4000 (approximate meters)
Type of water discharge:

- ____ Point discharge
- X Flood irrigation with gated pipe, 3200 ft. in length
- ____ Multiple point discharge at ____ locations

Typical monthly discharge schedule:

- X Seasonally from May through September
- ____ Continuous discharge all year
- ____ Periodically, explain:

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

- X none, relatively continuous discharge at predetermined rate for predetermined period
- ____ water depth in the wetland
- ____ water quality discharged to wetland
- ____ water quality at the wetland outflow
- ____ water quality at points inside the wetland
- ____ precipitation
- X other: Research Activities

Wetland vegetation harvested: No

Description of harvesting technique: No

Disposal or use of harvested material: No

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X	X	X	X
Total nitrogen content					
Dissolved nitrogen content	X	X	X	X	X
Total phosphorus content	X	X	X	X	X

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X	X	X	X
Suspended solids (total)	X	X			X
Volatile suspended solids	X				
Conductivity	X	X	X	X	X
pH	X	X	X	X	X
Chloride content	X	X	X	X	X
B.O.D.	X				
C.O.D.	X				X
Fecal coliform	X	X			X
Fecal strep	X				
Viruses	X				X
Heavy Metals	X				X
Organic chemicals/pesticides					
Other:					

3. Hydrology

Data known to be available for one or more years:
Complete water budgets X
Water depth measurements X
Soil elevations within the wetland (by survey with optical level or equivalent X
Estimates of subsurface water flow through the underlying soil X
Estimates of the fraction channel flow as opposed to sheet flow X
Details of water flow patterns across the wetland X

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.
Total phosphorus X
Total nitrogen X
Suspended solids
Chloride X
Heavy Metals X
Other:

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		X
Invertebrates		X
Algae		X
Microorganisms		X
Viruses		X
Sediments		X
Litter		X
Soil		X
Human use		X
Land use		X

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HUMBOLDT, Saskatchewan

The sewage treatment operation at Humboldt, 100 km east of Saskatoon is the culmination of three years of controlled experiments at the Saskatchewan Research Council on the use of aquatic plants for treating waste waters. The system at Humboldt consists of two 1/2 hectare lagoons and three separate 90 metre long ditches. They are stocked with cattail (Typha sp.) and bulrush (Scirpus sp.) the most common aquatic plants on the prairies. As a demonstration project, the treatment system has been designed to treat a part of the town's sewage from over 5,000 people. Raw (untreated) sewage from the town's primary lagoon is pumped through irrigation pipes with flow regulators into lagoons and ditches. After a period of time, from a few days to a few weeks, the effluent is discharged and another batch of sewage is pumped in.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Humboldt, Saskatchewan
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1979 to Present
Annual approximate discharge: 5-8 x 10^6 gal
Estimated affected area 1 ha
Wetland size 1 ha (area)
Distance from inlet to outlet 90 (approximate meters)
Type of water discharge:
X Point discharge
_____ Flood irrigation with gated pipe, _____ ft. in length
_____ Multiple point discharge at _____ locations
Typical monthly discharge schedule:
_____ Seasonally from _____ through _____
_____ Continuous discharge all year
X Periodically, explain: Batch, to Adequate Treatment

Factors which have actually been used to make decisions to modify the wastewater discharge rate:
_____ none, relatively continuous discharge at predetermined rate for predetermined period
_____ water depth in the wetland
_____ water quality discharged to wetland
X water quality at the wetland outflow
X water quality at points inside the wetland
_____ precipitation
_____ other: _____

Wetland vegetation harvested: Yes

Description of harvesting technique: Manual - shears

Disposal or use of harvested material: --

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X			
Total nitrogen content	X	X			
Dissolved nitrogen content	X	X			
Total phosphorus content	X	X			

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X			
Suspended solids (total)	X	X			
Volatile suspended solids					
Conductivity					
pH	X	X			
Chloride content					
B.O.D.	X	X			
C.O.D.					
Fecal coliform	X	X			
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: Organic Carbon	X	X			
Inorganic Carbon	X	X			
TDS	X	X			

3. Hydrology

Data known to be available for one or more years:

Complete water budgets ________

Water depth measurements X

Soil elevations within the wetland (by survey with optical level or equivalent ________

Estimates of subsurface water flow through the underlying soil ________

Estimates of the fraction channel flow as opposed to sheet flow ________

Details of water flow patterns across the wetland X

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus _____

Total nitrogen _____

Suspended solids _____

Chloride _____

Heavy Metals _____

Other: ________ _____

________ _____

________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae	X	X
Microorganisms	X	X
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Lakshman, G., "A Demonstration Project at Humboldt to Provide Tertiary Treatment to the Municipal Effluent Using Aquatic Plants - Progress Report 1979," Saskatchewan Research Council, Publ. No. E-820-13-1-E-80, March 1980.

Lakshman, G., "A Demonstration Project at Humboldt to Provide Tertiary Treatment to the Municipal Effluent Using Aquatic Plants - Progress Report 1980, Saskatchewan Research Council, Publ. No. E-820-4-E-81, April 1981.

JASPER, Florida

A significant research project on the use of a cypress strand for the treatment of secondary effluents is under way at this location. A small community in north Florida have been discharging wastewater to this wetland for a fair number of years. The project is under the joint auspices of Boyle Engineering Company and the Center for Wetlands at the University of Florida.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Jasper, Florida
Current as of July, 1981

1. Summary of System Management Technique

    Dates of operation: __________ to __________
    Annual approximate discharge: __________ gal
    Estimated affected area __________
    Wetland size __________ (area)
    Distance from inlet to outlet __________ (approximate meters)
    Type of water discharge:
    _____ Point discharge
    _____ Flood irrigation with gated pipe, _____ ft. in length
    _____ Multiple point discharge at _____ locations
    Typical monthly discharge schedule:
    _____ Seasonally from __________ through __________
    _____ Continuous discharge all year
    _____ Periodically, explain: ______________________________

    Factors which have actually been used to make decisions to modify the wastewater discharge rate:
    _____ none, relatively continuous discharge at predetermined rate for predetermined period
    _____ water depth in the wetland
    _____ water quality discharged to wetland
    _____ water quality at the wetland outflow
    _____ water quality at points inside the wetland
    _____ precipitation
    _____ other: ______________________________

    Wetland vegetation harvested: ______________________________

    Description of harvesting technique: ______________________________

    Disposal or use of harvested material: ______________________________

2. Overall Budgets for Water-borne Components

    Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate					
Total nitrogen content					
Dissolved nitrogen content					
Total phosphorus content					

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content					
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.					
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________________					
____________________					
____________________					

3. Hydrology

Data known to be available for one or more years:
Complete water budgets __________
Water depth measurements __________
Soil elevations within the wetland (by survey with optical level or equivalent __________
Estimates of subsurface water flow through the underlying soil ________
Estimates of the fraction channel flow as opposed to sheet flow _______
Details of water flow patterns across the wetland __________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.
Total phosphorus _____
Total nitrogen _____
Suspended solids _____
Chloride _____
Heavy Metals _____
Other: __________ _____
__________ _____
__________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Fritz, W. R., and S. C. Helle, "Natural Tertiary Treatment of Secondary Effluents by Wetlands in Florida," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

KESÄLAHTI, Finland

The Finnish process of allowing treated sewage to flow down ditches and percolate sideways into peat soils has been the subject of several studies - but almost all of the literature is in hard to get Finnish language sources.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Kesälahti, Finland

Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: __________ to __________

Annual approximate discharge: __________ gal

Estimated affected area __________

Wetland size __________ (area)

Distance from inlet to outlet __________ (approximate meters)

Type of water discharge:

_____ Point discharge

_____ Flood irrigation with gated pipe, _____ ft. in length

_____ Multiple point discharge at _____ locations

Typical monthly discharge schedule:

_____ Seasonally from __________ through __________

_____ Continuous discharge all year

_____ Periodically, explain: ____________________

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

_____ none, relatively continuous discharge at predetermined rate for predetermined period

_____ water depth in the wetland

_____ water quality discharged to wetland

_____ water quality at the wetland outflow

_____ water quality at points inside the wetland

_____ precipitation

_____ other: ____________________

Wetland vegetation harvested: ____________________

Description of harvesting technique: ____________________

Disposal or use of harvested material: ____________________

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate					
Total nitrogen content	X	X			
Dissolved nitrogen content					
Total phosphorus content	X	X			

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content					
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.	X	X			
C.O.D.					
Fecal coliform	X	X			
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________________					
____________________					
____________________					

3. Hydrology

Data known to be available for one or more years:
Complete water budgets __________
Water depth measurements __________
Soil elevations within the wetland (by survey with optical level or equivalent __________
Estimates of subsurface water flow through the underlying soil ________
Estimates of the fraction channel flow as opposed to sheet flow _______
Details of water flow patterns across the wetland __________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus _____
Total nitrogen _____
Suspended solids _____
Chloride _____
Heavy Metals _____
Other: __________ _____
__________ _____
__________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Surakka, S., and A. Kamppi, "Infiltration of wastewater into Peat Soil," SUO, 22, 3-4, pp. 51-57, 1971.

KINCHELOE, Michigan

The strategic air command base at this upper peninsula of Michigan location discharged the wastes and storm water runoff from the community of some 5,000 to 10,000 people for a period of some twenty years. The base closed in 1978, with a drastic reduction in the occupancy and the waste load from that location. No reliable discharge records are available, but a small amount of research work has been done by Grand Valley State College in Michigan as well as by the University of Michigan Wetlands Ecosystem Research Group. No official reports are available on this project. Nitrogen removals here are good, and phosphorus removals are not. Peat erosion has occurred at this site. A complete conversion of some 600-acres of wetland to a mono-culture of cattail has occurred.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Kinross, Michigan (Kincheloe)
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1955 to Present
Annual approximate discharge: 150×10^6 gal
Estimated affected area 400 Acres
Wetland size 500 Acres (area)
Distance from inlet to outlet 2,400 (approximate meters)
Type of water discharge:
X Point discharge
_____ Flood irrigation with gated pipe, _____ ft. in length
_____ Multiple point discharge at _____ locations
Typical monthly discharge schedule:
_____ Seasonally from __________ through __________
X Continuous discharge all year
_____ Periodically, explain: __________

Factors which have actually been used to make decisions to modify the wastewater discharge rate:
X none, relatively continuous discharge at predetermined rate for predetermined period
_____ water depth in the wetland
_____ water quality discharged to wetland
_____ water quality at the wetland outflow
_____ water quality at points inside the wetland
_____ precipitation
_____ other: __________

Wetland vegetation harvested: No

Description of harvesting technique: No

Disposal or use of harvested material: No

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X				
Total nitrogen content					
Dissolved nitrogen content	X	X			X
Total phosphorus content					

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X			X
Suspended solids (total)	X				
Volatile suspended solids					
Conductivity	X	X			X
pH	X	X			X
Chloride content	X	X			X
B.O.D.	X				
C.O.D.					
Fecal coliform	X				
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________					
____________					
____________					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets ________

Water depth measurements ___X___

Soil elevations within the wetland (by survey with optical level or equivalent ___X___

Estimates of subsurface water flow through the underlying soil ________

Estimates of the fraction channel flow as opposed to sheet flow ________

Details of water flow patterns across the wetland ________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus _____

Total nitrogen _____

Suspended solids _____

Chloride _____

Heavy Metals _____

Other: ________ _____

________ _____

________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		X
Litter		X
Soil		X
Human use		
Land use		

6. Principal Data Sources

Bevis, F. B., and R. H. Kadlec, "Effect of Long-Term Discharge of Wastewater on a Northern Michigan Wetland," (Abstract and Lists), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

LAKE BALATON, Hungary

Studies at the edge of this lake have shown that the lake margin wetland (a fresh water reed swamp) is successful in renovating wastewater.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Lake Balaton, Hungary

Current as of May, 1972

1. Summary of System Management Technique

Dates of operation: -- to --

Annual approximate discharge: -- gal

Estimated affected area 2000 m^2

Wetland size _____ (area)

Distance from inlet to outlet 140 (approximate meters)

Type of water discharge:

- __X__ Point discharge
- _____ Flood irrigation with gated pipe, _____ ft. in length
- _____ Multiple point discharge at _____ locations

Typical monthly discharge schedule:

- _____ Seasonally from _____ through _____
- __X__ Continuous discharge all year
- _____ Periodically, explain: _____

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

- __X__ none, relatively continuous discharge at predetermined rate for predetermined period
- _____ water depth in the wetland
- _____ water quality discharged to wetland
- _____ water quality at the wetland outflow
- _____ water quality at points inside the wetland
- _____ precipitation
- _____ other: _____

Wetland vegetation harvested: No

Description of harvesting technique: No

Disposal or use of harvested material: No

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate					
Total nitrogen content	X	X		X	
Dissolved nitrogen content	X	X		X	
Total phosphorus content	X	X		X	

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X		X	
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.					
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________					
____________					
____________					

3. Hydrology

Data known to be available for one or more years:
Complete water budgets ________
Water depth measurements ________
Soil elevations within the wetland (by survey with optical level or equivalent ________
Estimates of subsurface water flow through the underlying soil ________
Estimates of the fraction channel flow as opposed to sheet flow ________
Details of water flow patterns across the wetland ________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.
Total phosphorus _____
Total nitrogen _____
Suspended solids _____
Chloride _____
Heavy Metals _____
Other: ________ _____
________ _____
________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Toth, L., "Reeds Control Eutrophication of Balaton Lake," Water Research, Pergamon Press, Vol. 6, pp. 1533-1539, 1972.

LAS VEGAS, Nevada

Several hundred acres of cattails have been receiving treated wastewater from the metropolitan Las Vegas area (Clark County) since the plants were built. Water exits to the Las Vegas wash, thence to Lake Mead. Questions of water reuse and leaching of contaminants are important. Studies of the wetland are under way as part of a Regional planning effort.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Las Vegas, Nevada
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: ________ to Present
Annual approximate discharge: 30×10^9 gal
Estimated affected area 600 Acres
Wetland size 800 Acres (area)
Distance from inlet to outlet 5,500 (approximate meters)
Type of water discharge:

- ____ Point discharge
- ____ Flood irrigation with gated pipe, ____ ft. in length
- X Multiple point discharge at 3 locations

Typical monthly discharge schedule:

- ____ Seasonally from ________ through ________
- X Continuous discharge all year
- ____ Periodically, explain: ________

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

- X none, relatively continuous discharge at predetermined rate for predetermined period
- ____ water depth in the wetland
- ____ water quality discharged to wetland
- ____ water quality at the wetland outflow
- ____ water quality at points inside the wetland
- ____ precipitation
- ____ other: ________

Wetland vegetation harvested: No

Description of harvesting technique: No

Disposal or use of harvested material: No

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X				
Total nitrogen content	X	X			
Dissolved nitrogen content	X	X			
Total phosphorus content	X	X			

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X			
Suspended solids (total)	X	X			
Volatile suspended solids	X	X			
Conductivity	X	X			
pH	X	X			
Chloride content					
B.O.D.	X	X			
C.O.D.					
Fecal coliform	X	X			
Fecal strep	X	X			
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: TDS	X	X			
Nitrate, nitrite,	X	X }	for all	listed	para-
ammonia, total	X	X	meters		

Kjeldahl nitrogen, soluble ortho P, alkalinity, dissolved oxygen, temperature, total coliform

3. Hydrology

Data known to be available for one or more years:

Complete water budgets ____________

Water depth measurements ____________

Soil elevations within the wetland (by survey with optical level or equivalent ____________)

Estimates of subsurface water flow through the underlying soil ________

Estimates of the fraction channel flow as opposed to sheet flow ________

Details of water flow patterns across the wetland ____________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus _____

Total nitrogen _____

Suspended solids _____

Chloride _____

Heavy Metals _____

Other: __________ _____

__________ _____

__________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		
Vertebrates	X	
Invertebrates	X	
Algae	X	
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use	X	
Land use	X	

6. Principal Data Sources

Clark Co. 208, "Las Vegas Valley Water Resource Planning and Management," December 1978.

Clark Co. 208, "Las Vegas Wash," Interim Report #2, Water Quality Series, September 1977.

Clark Co. 208, "Las Vegas Wash," Interim Report #3, Water Quality Series, June 1977.

Clark Co. 208, "Las Vegas Wash," Interim Report #4, Water Quality Series, February 1978.

Clark Co. 208, "las Vegas Wash Engineering/Water Quality Management Study," Interim Report #1, June 1977.

Clark Co., "Las Vegas Wash: Environmental Assessment," November 1980.

Clark Co. 208, "Revised Water Quality Management Plan," December 1979.

Clark Co. 208, "Subsurface Water," Interim Report #1, Water Quality Series, May 1977.

Clark Co. 208, "Subsurface Water," Interim Report #2, Water Quality Series, September 1977.

Clark Co. 208, "Subsurface Water," Interim Report #2, Water Quality Series, March 1978.

Culp, Wesner & Culp, "Analysis of Water Quality in Las Vegas Wash," July-November 1979.

Ecological Research Associates, "A Proposal to Study the Biological Aspects of Nutrient Stripping in the Las Vegas Wash Wetlands," April 1979.

Krenkel, P. A., and L. P. Smith, "A Study of the Characteristics of the Las Vegas Wash Regarding it's Ability to Remove Phosphorus, Nitrogen and Carbon," Proposal to Clark Co., 1978.

LISTOWEL, Ontario

This is an artificial marsh consisting of five independent systems constructed in the late summer of 1980 for the treatment of aerated raw sewage and partially treated lagoon effluent. It is being used on a year-round basis to treat wastewater. The wetland plant community was established with no difficulty at the end of summer 1980. This wetland site is currently functioning in a very efficient manner to reduce various water quality parameters to acceptable levels. Harvest of the vegetation is carried out at the site, and several pathogenic organisms are also monitored at this location. No official reports have issued from the facility as yet.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Listowel, Ontario (Artificial)
Current as of September, 1981

1. Summary of System Management Technique

Dates of operation: 1980 to Present
Annual approximate discharge: 15 x 10^6 gal
Estimated affected area 2.5 Acres
Wetland size 2.5 Acres (area)
Distance from inlet to outlet 330 Chan-(approximate meters)
Type of water discharge: neled marsh, 66 open marsh, 462 System I

X Point discharge
_____ Flood irrigation with gated pipe, _____ ft. in length
_____ Multiple point discharge at _____ locations

Typical monthly discharge schedule:

_____ Seasonally from _____ through _____
X Continuous discharge all year
_____ Periodically, explain: _____

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

_____ none, relatively continuous discharge at predetermined rate for predetermined period
X water depth in the wetland
_____ water quality discharged to wetland
X water quality at the wetland outflow
_____ water quality at points inside the wetland
_____ precipitation
_____ other: _____

Wetland vegetation harvested: Yes, July and August 1981

Description of harvesting technique: Tractor and Mower

Disposal or use of harvested material: None at this time

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X	X		
Total nitrogen content	X	X			
Dissolved nitrogen content	X	X			
Total phosphorus content	X	X			

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X			
Suspended solids (total)	X	X			
Volatile suspended solids					
Conductivity	X	X			
pH	X	X			
Chloride content	X	X			
B.O.D.	X	X			
C.O.D.					
Fecal coliform	X	X			
Fecal strep	X	X			
Viruses					
Heavy Metals		X)	Twice Yearly		
Organic chemicals/pesticides		X			
Other: Pseudomonas	X	X			
Tersinia	X	X			
Salmonella. / Closteridum	X	X			

3. Hydrology

Data known to be available for one or more years:

Complete water budgets X

Water depth measurements X

Soil elevations within the wetland (by survey with optical level or equivalent (attempting to establish methodology)

Estimates of subsurface water flow through the underlying soil ____

Estimates of the fraction channel flow as opposed to sheet flow ____

Details of water flow patterns across the wetland X

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X

Total nitrogen X

Suspended solids X /Not yet available

Chloride X

Heavy Metals ____

Other: ____ ____

____ ____

____ ____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates	X	
Invertebrates	X	
Algae	X	X
Microorganisms		X
Viruses		
Sediments		X
Litter		X
Soil		X
Human use		
Land use		

6. Principal Data Sources

Slaughter, R., and I. Wile, "Natural and Artificial Marshes for Sewage Treatment in Ontario," (Abstract), Presented at Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Wile, I., "An Experimental Approach to Wastewater Treatment Using Natural and Artificial Wetlands," Progress Report, Oct. 27, 1980.

Wile, I., "Experimental Marsh Project at Listowel," Progress Report (unpublished), 1980.

MT. VIEW, California

The Mt. View Sanitary District developed artificial marshes for wildlife habitat enhancement, utilizing treated wastewater. This is a relatively small site which receives secondary effluent, and does not accomplish much in the way of water quality improvement, because of the high loading rate. However, a demonstrable impact on the biota of the region has been documented. Wetland consists of a fresh water/cattail/open water environment, with intentional habitat design. It has been in operation for approximately four years.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Mt. View Sanitary District, California /
Current as of July, 19 81 (Artificial)

1. Summary of System Management Technique

Dates of operation: 1974 to Present
Annual approximate discharge: 255 x 10^6 gal
Estimated affected area 21 Acres
Wetland size 21 Acres (area)
Distance from inlet to outlet 400 (approximate meters)

Type of water discharge:

X Point discharge
_____ Flood irrigation with gated pipe, _____ ft. in length
_____ Multiple point discharge at _____ locations

Typical monthly discharge schedule:

_____ Seasonally from __________ through __________
X Continuous discharge all year
_____ Periodically, explain: __________

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

X none, relatively continuous discharge at predetermined rate for predetermined period
_____ water depth in the wetland
_____ water quality discharged to wetland
_____ water quality at the wetland outflow
_____ water quality at points inside the wetland
_____ precipitation
_____ other: __________

Wetland vegetation harvested: No

Description of harvesting technique: No

Disposal or use of harvested material: No

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X				
Total nitrogen content	X	X			
Dissolved nitrogen content	X	X			
Total phosphorus content	X	X			

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content					
Suspended solids (total)	X	X			
Volatile suspended solids					
Conductivity					
pH	X	X			
Chloride content					
B.O.D.	X	X			
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: __________					
__________					
__________					

3. Hydrology

Data known to be available for one or more years:
Complete water budgets ________
Water depth measurements ___X___
Soil elevations within the wetland (by survey with optical level or equivalent ________
Estimates of subsurface water flow through the underlying soil ________
Estimates of the fraction channel flow as opposed to sheet flow ________
Details of water flow patterns across the wetland ________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus _____
Total nitrogen _____
Suspended solids _____
Chloride _____
Heavy Metals _____
Other: ________ _____
________ _____
________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants	X	
Vertebrates		X
Invertebrates		X
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Demgen, F. C., "Water Used One More Time: Treated Wastewater for Wildlife," Outdoor California, pp. 28-29, March-April 1979.

Demgen, F. C., Mt. View Sanitary District, "Wetlands Creation for Habitat and Treatment - At Mt. View Sanitary District, California," In: Seminar Proceedings Aquaculture Systems for Wastewater Treatment, Bastian and Reed, Eds., The Univ. of California at Davis, CA, US EPA A30-9-80-006, Publ. No. MCD-67, Sept. 1979.

Demgen, F. C., and B. J. Blubaugh, "Mt. View Sanitary District Marsh Enhancement Pilot Program," Progress Report No. 3, to the Mt. View Sanitary District, June 1977.

Demgen, F. C., and J. W. Nute, "Wetland Creation Using Secondary Treated Wastewater," In: American Water Works Association Research Foundation, Proceedings of the Water Reuse Symposium at Washington, DC, Vol. 1, Denver, CO, pp 727-739, March 25-30, 1979.

Demgen, F. C., and J. W. Nute, "Wetlands Enhancement Using Secondary Effluent," Paper Presented at the National Conference on Environmental Engineering, Research Development and Design, Kansas City, Missouri, July 10-12, 1978.

EBC Company, "The Mash-Forest System: A Pleasant and Positive Answer for Water Reclamation, pp. 1-9, 1979.

Nute, J. W., F. Demgen, "The Wetlands Wastewater Management Alternative," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Nute, J. W., W. E. Nute, "Marsh/Forest Demonstration Project Feasibility Assessment," J. Warren Nute, Inc., Civil and Sanitary Engineers, pp. 1-15, 1979.

SEYMOUR, Wisconsin

The research team from the University of Wisconsin at Oshkosh also conducted a study at this location. Artificial basins were constructed and planted with bulrushes on different substrates. Reductions in nutrients were not encouraging. Significant reductions in BOD and COD were measured as well as significant reductions in suspended solids in some cases. These were fairly deep water retention basins that were used in this study. Data were acquired during 1975.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Seymour, Wisconsin (Artificial)
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1973 to 1975
Annual approximate discharge: 100,000 gal
Estimated affected area 112 m^2
Wetland size 112 m^2 (area)
Distance from inlet to outlet 19.3 (approximate meters)
Type of water discharge:

X Point discharge
_____ Flood irrigation with gated pipe, _____ ft. in length
_____ Multiple point discharge at _____ locations

Typical monthly discharge schedule:

X Seasonally from June through November
_____ Continuous discharge all year
_____ Periodically, explain:

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

X none, relatively continuous discharge at predetermined rate for predetermined period
_____ water depth in the wetland
_____ water quality discharged to wetland
_____ water quality at the wetland outflow
_____ water quality at points inside the wetland
_____ precipitation
_____ other:

Wetland vegetation harvested: Bulrushes

Description of harvesting technique: Cutting

Disposal or use of harvested material: No Data

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X	N/A	N/A	
Total nitrogen content					
Dissolved nitrogen content					
Total phosphorus content	X	X	N/A	N/A	

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content					
Suspended solids (total)	X	X	N/A	N/A	
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.	X	X	N/A	N/A	
C.O.D.	X	X	N/A	N/A	
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________					
____________					
____________					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets __X__

Water depth measurements __X__

Soil elevations within the wetland (by survey with optical level or equivalent __X__

Estimates of subsurface water flow through the underlying soil __X__

Estimates of the fraction channel flow as opposed to sheet flow __X__

Details of water flow patterns across the wetland __X__

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus __X__

Total nitrogen _____

Suspended solids __X__

Chloride _____

Heavy Metals _____

Other: __________ _____

__________ _____

__________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

6. Principal Data Sources

Spangler, F. L., W. E. Sloey, C. W. Fetter, Jr., "Artificial and Natural Marshes as Wastewater Treatment Systems in Wisconsin," Proceeding of the Symposium on Freshwater Wetlands and Sewage Effluent Disposal, The Univ. of Mich., Ann Arbor, MI, pp. 215-240, May 10-11, 1976.

Spangler, F. L., W. E. Sloey, C. W. Fetter, Jr., "Wastewater Treatment by Natural and Artificial Marshes," Prepared for Robert S. Kerr Environmental Research Lab., Ada, OK, (EPA - 600/2-76-207), NTIS Report (PB-259 992), pp. 1-171, Sept. 1976.

SUISUN CITY, California

Wastewater from a sanitary treatment plant near the Suisun marsh is being used in Duck Club management there. An attempt is being made here to utilize wastewater solely for habitat improvement.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Suisun City, California
Current as of August, 1981

1. Summary of System Management Technique

Dates of operation: 1977 to 1982
Annual approximate discharge: 5.0×10^6 gal
Estimated affected area 300 Acres
Wetland size 84,000 Acres (area)
Distance from inlet to outlet 400 (approximate meters)
Type of water discharge:

X Point discharge
___ Flood irrigation with gated pipe, ___ ft. in length
___ Multiple point discharge at ___ locations

Typical monthly discharge schedule:

X Seasonally from October 1 through May 15
___ Continuous discharge all year
X Periodically, explain: Continuous, Except Periodically in February and March

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

___ none, relatively continuous discharge at predetermined rate for predetermined period
X water depth in the wetland
X water quality discharged to wetland
X water quality at the wetland outflow
X water quality at points inside the wetland
X precipitation
X other: Tests - Diurnal Dissolved Oxygen, Water Temp., BOD, Inpond NH_3-N, NO_3-N, PO_4

Wetland vegetation harvested: Yes, Limited Areas

Description of harvesting technique: Mowing

Disposal or use of harvested material: Waterfowl Forage

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X	X		X
Total nitrogen content	X	X	X		X
Dissolved nitrogen content	X	X	X		X
Total phosphorus content	X	X	X		X

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X	X		X
Suspended solids (total)					
Volatile suspended solids					
Conductivity	X	X	X		X
pH	X	X	X		X
Chloride content	X	X	X		X
B.O.D.	X	X	X		X
C.O.D.					
Fecal coliform	X	X	X		X
Fecal strep					
Viruses					
Heavy Metals	X	X	X		X
Organic chemicals/pesticides					
Other: Dissolved Oxygen	X	X	X		X
____________					
____________					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets __________

Water depth measurements X

Soil elevations within the wetland (by survey with optical level or equivalent __________

Estimates of subsurface water flow through the underlying soil X

Estimates of the fraction channel flow as opposed to sheet flow _______

Details of water flow patterns across the wetland __________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus _____

Total nitrogen _____

Suspended solids _____

Chloride _____

Heavy Metals _____

Other: __________ _____

__________ _____

__________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants	X	
Vertebrates		
Invertebrates	X	
Algae	X	X
Microorganisms		
Viruses		
Sediments		
Litter		
Soil	X	
Human use		
Land use		

6. Principal Data Sources

Cederquist, N., "Using Wastewater for Duck Club Management in the Suisun Marsh of California," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Cederquist, N., "Wastewater Reclamation and Reuse Pilot Demonstration Program for the Suisun Marsh," Progress Report, U. S. Dept. of the Interior Bureau of Reclamation, Mid-Pacific Region, Water Quality Branch, Sacramento, California, March 1977.

VERMONTVILLE, Michigan

Slow seepage from surface (flood) irrigation fields receiving effluent from facultative stabilization ponds led to the establishment of a volunteer wetland at this location. The counsulting firm of Williams & Works, Inc. conducted a study of the water quality and species composition at that location for the National Science Foundation. This study spans 1978 and 1979.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Vermontville, MI (volunteer)
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1978 to 1979
Annual approximate discharge: 25×10^6 gal
Estimated affected area 11.5 Acres
Wetland size 11.5 Acres (area)
Distance from inlet to outlet NA-seepage wetlands (approximate meters)
Type of water discharge:

- _____ Point discharge
- _____ Flood irrigation with gated pipe, _____ ft. in length
- __X__ Multiple point discharge at 12 ± locations

Typical monthly discharge schedule:

- __X__ Seasonally from June through October or November
- _____ Continuous discharge all year
- _____ Periodically, explain: _____

Factors which have actually been used to make decisions to modify the wastewater discharge rate:

- __X__ none, relatively continuous discharge at predetermined rate for predetermined period
- _____ water depth in the wetland
- _____ water quality discharged to wetland
- _____ water quality at the wetland outflow
- _____ water quality at points inside the wetland
- _____ precipitation
- _____ other: _____

Wetland vegetation harvested: No

Description of harvesting technique: No

Disposal or use of harvested material: No

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X		X		
Total nitrogen content	X		X	X	X
Dissolved nitrogen content	X	X	X	X	X
Total phosphorus content					

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X	X	X	X
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content	X	X	X	X	X
B.O.D.					
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ________					
________					
________					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets __X__

Water depth measurements ______

Soil elevations within the wetland (by survey with optical level or equivalent ______

Estimates of subsurface water flow through the underlying soil __X__

Estimates of the fraction channel flow as opposed to sheet flow ______

Details of water flow patterns across the wetland ______

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus __X__

Total nitrogen ____

Suspended solids ____

Chloride __X__

Heavy Metals ____

Other: ________ ____

________ ____

________ ____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		X
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		
Soil		
Human use		
Land use		

} No wetland prior to irrigation

6. Principal Data Sources

Bevis, F., "Ecological Considerations in the Management of Wastewater - Engendered Volunteer Wetlands," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Sutherland, J. C., "The Vermontville, Michigan, Wastewater-Grown Volunteer Seepage Wetlands: Water Quality and Engineering Implications," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Sutherland, J. C., and F. B. Bevis, "Reuse of Municipal Wastewater by Volunteer Fresh-Water Wetlands," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Williams, T. C., and J. C. Sutherland, "Engineering, Energy and Effectiveness Features of Michigan Tertiary Wastewater Treatment Systems," Seminar on Aquaculture Systems for Wastewater Treatment, University of California, Davis, CA, September 11-12, 1979.

Williams and Works, "Reuse of Municipal Wastewater by Volunteer Fresh-Water Wetlands," (ENV-20273), Interim Report to the National Science Foundation, April 1979.

WALDO, Florida

A cypress strand at Waldo has been receiving primarily treated municipal wastewater for a period of some twenty years. The site has been researched in some detail by personnel from the Center for Wetlands at Gainesville. Significant increases in cypress growth are documented at this site.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Waldo, Florida
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1935 to Present
Annual approximate discharge: 30×10^6 gal
Estimated affected area 2.6 ha
Wetland size 2.6 ha (area)
Distance from inlet to outlet 400 (approximate meters)

Type of water discharge:
- X Point discharge
- ____ Flood irrigation with gated pipe, ____ ft. in length
- ____ Multiple point discharge at ____ locations

Typical monthly discharge schedule:
- ____ Seasonally from ____ through ____
- X Continuous discharge all year
- ____ Periodically, explain: ____

Factors which have actually been used to make decisions to modify the wastewater discharge rate:
- X none, relatively continuous discharge at predetermined rate for predetermined period
- ____ water depth in the wetland
- ____ water quality discharged to wetland
- ____ water quality at the wetland outflow
- ____ water quality at points inside the wetland
- ____ precipitation
- ____ other: ____

Wetland vegetation harvested: No

Description of harvesting technique: No

Disposal or use of harvested material: No

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X	X	X	
Total nitrogen content					
Dissolved nitrogen content					
Total phosphorus content	X	X	X	X	X

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X	X	X	X
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.					
C.O.D.					
Fecal coliform					
Fecal strep					
Viruses					
Heavy Metals					
Organic chemicals/pesticides					
Other: ____________					
____________					
____________					

3. Hydrology

Data known to be available for one or more years:

Complete water budgets ___X___

Water depth measurements ___X___

Soil elevations within the wetland (by survey with optical level or equivalent ________

Estimates of subsurface water flow through the underlying soil ___X___

Estimates of the fraction channel flow as opposed to sheet flow ______

Details of water flow patterns across the wetland ________

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus __X__

Total nitrogen _____

Suspended solids _____

Chloride _____

Heavy Metals _____

Other: ________ _____

________ _____

________ _____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants		X
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		X
Soil		X
Human use		
Land use		

6. Principal Data Sources

Fritz, W. R., and S. C. Helle, "Natural Tertiary Treatment of Secondary Effluents by Wetlands in FLorida," (Abstract), Presented at the Conference on Freshwater Wetlands and Sanitary Wastewater Disposal, Higgins Lake, MI, July 10-12, 1979.

Fritz, W. R., and S. C. Helle, "Cypress Wetlands for Tertiary Treatment," In: Aquaculture Systems for Wastewater Treatment: Seminar Proceedings and Engineering Assessment, R. K. Bastian and S. C. Reed (Project Officers), EPA-430/9-80-006, U. S. Environmental Protection Agency, Office of Water Program Operations, Municipal Construction Division, Washington, DC, pp. 75-81, 1979.

Nessel, J. K., "Distribution and Dynamics of Organic Matter and Phosphorus in a Sewage Enriched Cypress Swamp," Master's Thesis, Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL, pp. 159, 1978.

Odum, H. T., and K. C. Ewel, (eds.), "Cypress Wetlands for Water Management - Recycle and Conservation," Fifth Annual Report to NSF and Rockefeller Foundation, NSF Grant # PFR-7706013 A02, RF Grant # RF-76034, Center for Wetlands, University of Florida, Gainesville, FL, April 1980.

WILDWOOD, Florida

Fresh water marshes at this location were shown to remove nutrients, in studies performed by Boyt, _et al_. This study led to the more closely controlled study at Clermont, Florida. A fairly large number of parameters were studied at this site, including metals and coliforms.

DATA COLLECTED FOR WETLAND AWT OPERATIONS

Location and/or Name of Site: Wildwood, Florida
Current as of July, 1981

1. Summary of System Management Technique

Dates of operation: 1957 to Present
Annual approximate discharge: 55 x 10^6 gal
Estimated affected area 500 Acres
Wetland size 500 Acres (area)
Distance from inlet to outlet 9.--- (approximate meters)
Type of water discharge:
X Point discharge
_____ Flood irrigation with gated pipe, _____ ft. in length
_____ Multiple point discharge at _____ locations
Typical monthly discharge schedule:
_____ Seasonally from __________ through __________
X Continuous discharge all year
_____ Periodically, explain: ____________________

Factors which have actually been used to make decisions to modify the wastewater discharge rate:
X none, relatively continuous discharge at predetermined rate for predetermined period
_____ water depth in the wetland
_____ water quality discharged to wetland
_____ water quality at the wetland outflow
_____ water quality at points inside the wetland
_____ precipitation
_____ other: ____________________

Wetland vegetation harvested: No

Description of harvesting technique: ____________________

Disposal or use of harvested material: ____________________

2. Overall Budgets for Water-borne Components

Information known to exist covering one or more years:

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Water flow rate	X	X	X	X	
Total nitrogen content	X	X	X		X
Dissolved nitrogen content	X	X	X		X
Total phosphorus content	X	X	X		X

	Wastewater discharge	Effluent from wetland to receiving waters	Natural inlet flows to the wetland	Subsurface waters	Surface waters
Dissolved phosphorus content	X	X	X		X
Suspended solids (total)					
Volatile suspended solids					
Conductivity					
pH					
Chloride content					
B.O.D.					
C.O.D.					
Fecal coliform	X	X	X		X
Fecal strep	X	X	X		X
Viruses					
Heavy Metals	X	X	X		X
Organic chemicals/pesticides					
Other: Carbon	X	X	X		X

3. Hydrology

Data known to be available for one or more years:

Complete water budgets X

Water depth measurements ______

Soil elevations within the wetland (by survey with optical level or equivalent ______

Estimates of subsurface water flow through the underlying soil X

Estimates of the fraction channel flow as opposed to sheet flow ______

Details of water flow patterns across the wetland ______

4. Detailed Component Balances

Detailed budgets known to have been prepared for one or more years. A "detailed budget" is defined here as accounting for a particular component, considering its transport between water and soil, plants, algae, or other physically identifiable entity within the wetland.

Total phosphorus X

Total nitrogen X

Suspended solids ____

Chloride ____

Heavy Metals X

Other: ______ ____

______ ____

______ ____

5. Ecosystem Changes

Studies have been made of the following changes in the wetland since wastewater discharge began. It is indicated whether these studies are qualitative or quantitative observations.

	qualitative study	quantitative study
Vascular plants	X	X
Vertebrates		
Invertebrates		
Algae		
Microorganisms		
Viruses		
Sediments		
Litter		X
Soil		
Human use		
Land use		

6. Principal Data Sources

Boyt, F. L., S. E. Bayley, and J. Zoltek, Jr., "Removal of Nutrients from Treated Municipal Wasteland by Wetland Vegetation," J. Water Poll. Contr. Fed., 49, pp. 789-799, 1977.

Odum, H. T., and S. Brown, "Regional Implications of Sewage Effluent Application on Cypress Domes," (Abstract), Proceedings of the Symposium on Freshwater Wetlands and Sewage Effluent Disposal, The Univ. of Mich., Ann Arbor, MI, pp. 329-330, May 10-11, 1976.